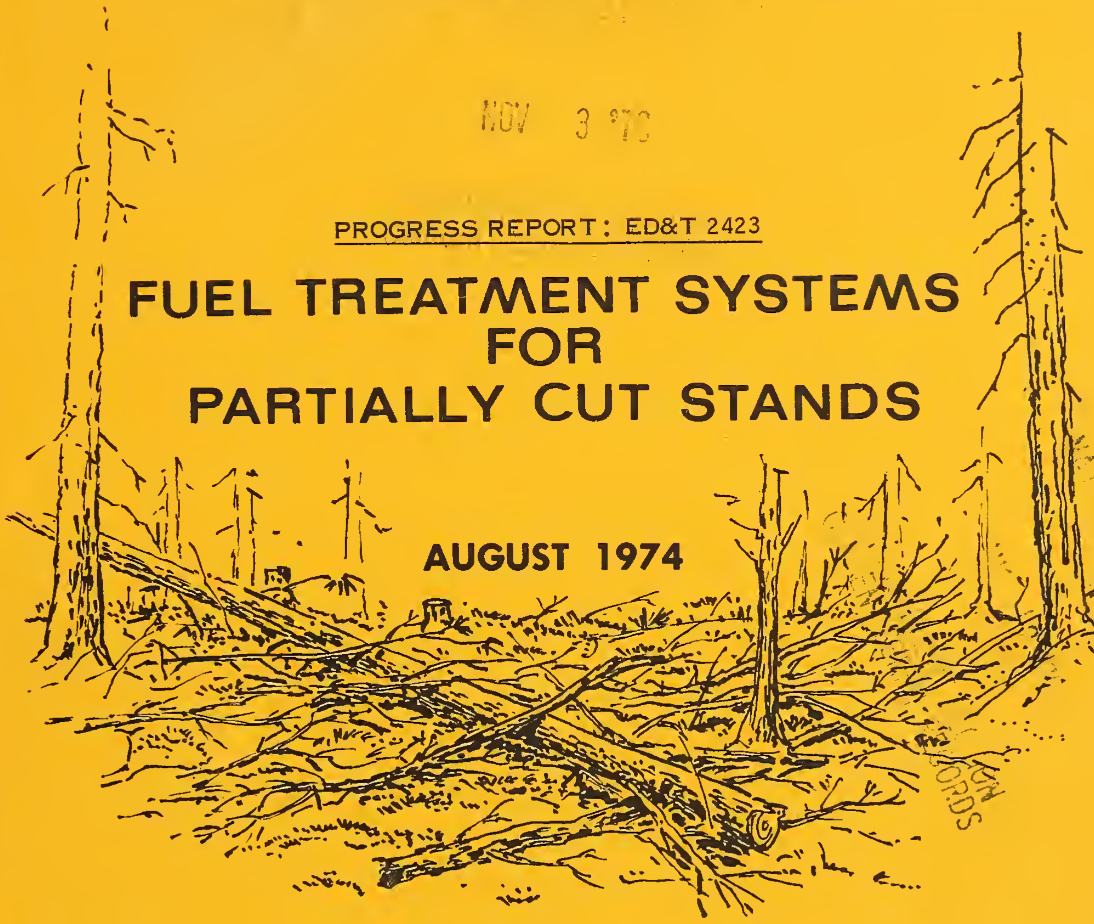
project record

PROGRESS REPORT: ED&T 2423

FUEL TREATMENT SYSTEMS FOR PARTIALLY CUT STANDS



AUGUST 1974

U.S. Department of Agriculture
Forest Service
Equipment Development Center
Missoula, Montana

PROJECT RECORD

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FUEL TREATMENT SYSTEMS FOR PARTIALLY CUT STANDS

By

DONALD J. WEATHERHEAD

FORESTER

August 1974

USDA Forest Service
Equipment Development Center
Missoula, Montana

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INTRODUCTION

Fuels management is becoming an ever increasingly important and more difficult task to accomplish each year. Frequently, the treatment of slash[1/] in partial cuts is more difficult than treatment in clearcuts, primarily because consideration must be given to the residual stand. Partial cutting is an ambiguous term which includes any type of commercial harvesting other than clearcutting, ranging in degree of cutting from a seed tree cut to a very light salvage, sanitation or selection cut.

With recent public criticism of clearcutting, various types of partial cutting are receiving much more widespread use. In addition, as land managers move toward more intensive management, partial cutting becomes more widely practiced in the form of intermediate cuts. The Northern Region (Region 1) can be used to illustrate the increased use of partial cutting. Three years ago partial cuts composed approximately 45 percent of the Region's total planned sell as compared to approximately 80 percent in fiscal year 1974.

Recently, the importance of adequate slash treatment has been reemphasized and the use of extra fire protection as a slash treatment alternative in partial cuts has been deemphasized. It is estimated that in Region 1 there are over 400,000 acres of untreated slash in partial cuts.[2/] Admittedly, part of this acreage may not need any special treatment; however, from the standpoint of fire hazard alone, treatment is probably needed on a significant portion of this total acreage.

The Missoula Equipment Development Center (MEDC) began a project in FY '74 investigating fuel treatment systems for partially cut stands. The following is an interim report which describes the Center's plans for the project and results of the first year's efforts.

PROBLEM IDENTIFICATION

Initially, a considerable amount of time and effort was expended by a 5-man team, comprised of engineers and foresters, identifying current problems in fuels management in partial cuts and determining what contribution MEDC could make in finding solutions to the problems. A literature search was conducted. Field personnel were contacted and queried on the subject. The project was discussed with personnel involved in slash projects at San Dimas Equipment Development Center, the Northern Forest Fire Laboratory (Intermountain Forest and Range Experiment Station), the Forest Residues Reduction Project (Pacific Northwest Forest and Range Experiment Station), and the Coram Logging Study (Intermountain Forest and Range Experiment Station). Efforts have been made to assure coordination with these research projects and to avoid duplication of work. In addition, the team visited several partial cut sales with local field personnel and discussed their slash problems on the Lolo, Kootenai, Flathead, and Clearwater National Forests in Montana and Idaho.

It was determined that few land managers are able to visualize or predict the resulting slash on a partial cut sale prior to harvesting. As a consequence, in many instances, the resulting slash is accepted as a gigantic "surprise package" after logging, and satisfactory treatment may be impossible. On the other hand, treatment may be possible but funding may be insufficient to accomplish the task if an adequate allowance was not made during presale planning. In general, adequate data and planning tools relative to fuel treatment systems are not available to help accomplish good presale planning. Since slash treatment on Forest Service sales is considered a logging cost, an estimate of the total treatment cost is necessary when the sale appraisal is prepared. If the estimate is too low, additional funding may be sought from appropriated monies which are extremely difficult to obtain, if not

1/ Slash or fuel in this report refers to residues such as foliage, twigs, branch wood, bark, rotten wood, cull logs, and trees unmerchantable because of defect or size. This includes not only material resulting from harvesting but also material existing prior to logging.

2/ Based on a conversation with Jack Alle[illegible], Div. of Timber Mgt., Region 1, USDA Forest Service.

impossible. Even if appropriated monies are obtained, they may be inadequate to accomplish the necessary work. Therefore, adequate treatment may not be achieved. Ideally, a land manager should be able to predict his fuel treatment needs prior to harvesting and be aware of feasible treatment alternatives and their associated costs.

In summary, the problem is that most land managers have no reliable or accurate method of predicting fuel residues resulting from a particular partial cut sale. Further, it is extremely difficult to estimate the type of treatment that is necessary or suitable to reduce fuels to an "acceptable" level; a level that is generally not known in quantitative terms. Also, it is difficult to estimate the associated costs of a particular fuel treatment for a particular set of sale conditions. Experienced or historical costs, even for the most commonly used slash treatments, are reported on a per acre basis and provide little reference to variables such as slope, fuel loading, residual spacing, etc. As a result, the range of experienced costs for a particular fuel treatment is extremely broad and the average cost is of questionable value for planning. Finally, land managers may not be familiar with all treatment methods that are feasible for a particular sale.

GOALS AND OBJECTIVES

Based upon our problem analysis, the goal of the project is to develop a decision-making model or technique, which is better than currently used methods, to predict fuel loadings, fuel treatment needs, treatment alternatives and associated costs prior to harvesting for a specific set of sale conditions. Plans are to develop an operational decision-making model within another year.

Eventually, increased utilization of logging wastes may eliminate the problem of slash disposal. Considerable work is underway by the Forest Products Laboratory and others to find ways of increasing utilization and developing markets for logging residues. But complete utilization is not yet a reality in many areas, and slash disposal is still a problem. So we plan to provide aids to the fieldman that can be used in making decisions to manage slash in partial cuts as long as the problem exists.

Because useful fuel information from past studies is available for tree species in Region 1, and it is easier financially and more expedient to contact field personnel in this locale, the study is initially being limited to the Northern Region. However, we expect that many techniques developed specifically for this area may be applicable in other Regions with little or no modification.

Specific objectives which will lead toward the attainment of the project goal are as follows:

1. Develop a technique to determine feasible fuel treatment methods and a means to estimate their effectiveness and cost under various sale conditions.

2. Provide a means to examine the influence of various management decisions on fuel treatment costs and effectiveness (sensitivity analysis).

3. Develop a scheme to quantify fuel treatment objectives.

4. Develop a computer program based on existing known relationships which can easily be used by a land manager to predict fuel loadings by size classes prior to harvesting for a particular sale (fuel prediction model).

The final results of the project will be the development of a decision-making model similar to the flow chart in figure 1. In reference to figure 1, a decision-maker is confronted with one of two situations: either select a fuel treatment system after harvesting or select a fuel treatment system prior to harvesting. As mentioned previously, we are mainly concerned with the latter situation; however, the final model could handle either situation.

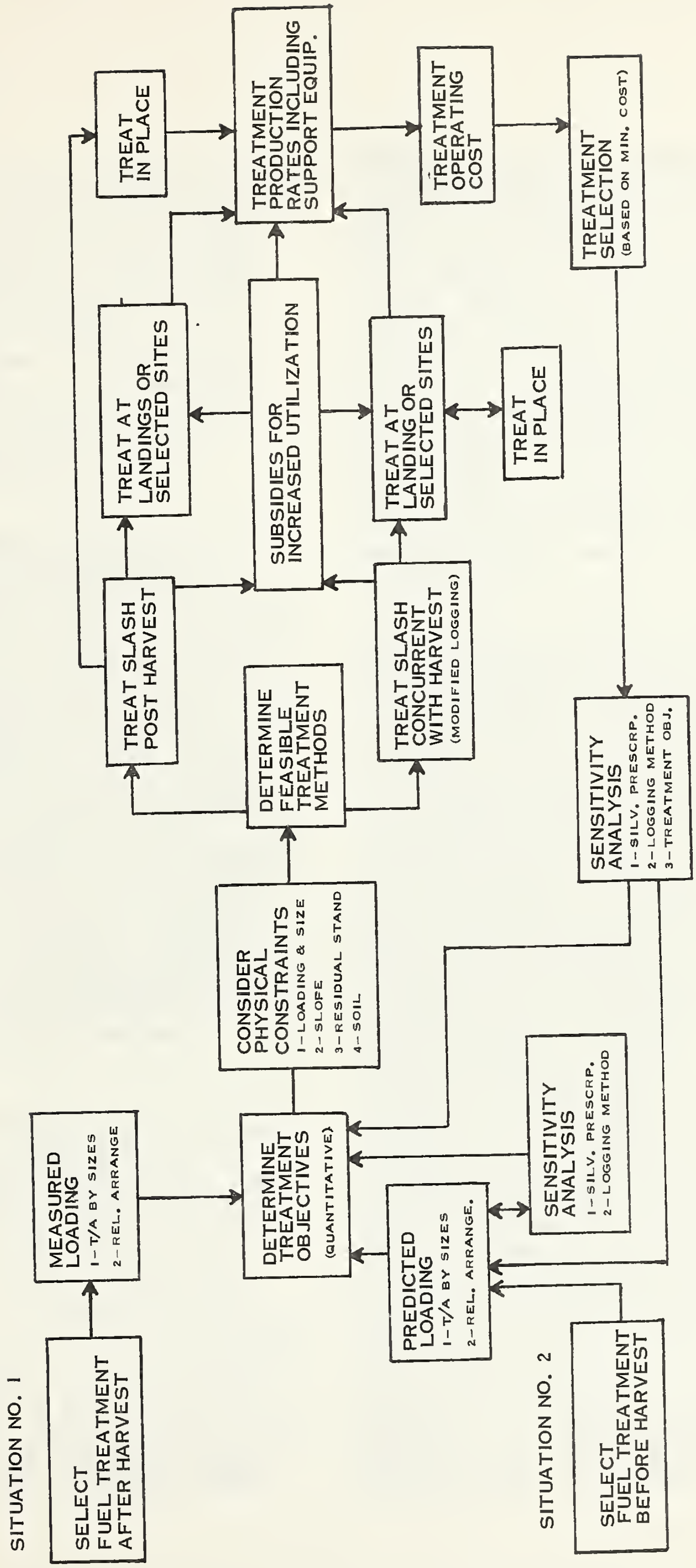


Figure 1.--Fuel treatment selection model (a decision-making tool).

Assuming situation No. 2 is pursued, the land manager will use the fuel prediction model to estimate fuel loadings resulting from harvesting based on his particular set of sale conditions. At this point the land manager has the option of conducting a sensitivity analysis. He can repeatedly vary such things as the silvicultural prescription, falling of snags or estimated damage of small unmerchantable trees and observe their impact on the fuel loading predicted. In other words, he can see how sensitive fuel loading is to particular variables.

Once a fuel loading estimate is obtained, the land manager must quantitatively specify his treatment objectives which will be based upon a technique which will be developed. In addition to the physical constraint of fuel loading, other variables such as slope, residual spacing and soils are considered in the model. Based upon physical constraints and treatment objectives, feasible treatment alternatives are determined. In other words, the combination of treatment objectives and physical constraints serve as a filter to eliminate obviously infeasible treatments. For example: if the treatment objective was to reduce fuel loading in fuels less than 4 inches in diameter to 10 tons or less per acre and present loading in this size class was greater than this, obviously any method of crushing would not meet the treatment objective.

There are at least three major categories of treatments. First, there is a category that includes fuel treatments which are conducted after harvesting has been completed. These treatments can take place either at selected sites such as landings or treat the slash in place or a combination. Another category considers treating the slash concurrently with harvesting by modifying the logging system. For example: whole-tree skidding and subsequent chipping or incinerator burning tops at or near landings during the harvesting operation or using a feller-buncher to concentrate tops would be considered a treatment method. Assuming there are additional costs associated with this type of modified logging as compared to standard logging methods, these additional costs would be treated as slash treatment cost. The final category of fuel treatments includes subsidies which are provided to entice the purchaser to remove certain components of the total fuel loading. For example: it may be feasible to pay a certain amount for the removal of cull logs disregarding whether the purchaser makes a profit by selling the cull logs. If the removal of the cull logs significantly reduces the total fuel treatment task, the subsidy used to obtain the removal would be treated as a slash treatment cost.

After feasible treatment methods are determined by considering fuel loadings, treatment objectives and physical constraints, efforts are directed toward determining the respective cost of each treatment. One can use production rates and operating costs to estimate the total cost for each feasible treatment method. A significant portion of the project will involve the development of production rates for various fuel treatments under various conditions. The cost for a particular treatment will then be the product of the production rate times the operating cost. It appears reasonable to assume that once production rates are developed, they will remain valid unless new technology is developed. Therefore, treatment costs can easily be updated by revising operating costs. Finally, once treatment costs are obtained for feasible treatments, the treatment selection could be based on a minimum cost since all treatments which have been considered meet the treatment objectives. However, the decision-maker has the option of rejecting all treatments and utilizing a sensitivity analysis to obtain a new set of feasible treatments and associated costs. For example, he could change one or all of the following: silvicultural prescription, logging method or treatment objective. If this route were pursued, then a new set of feasible treatments and costs would be obtained.

MAJOR TASKS AND RESULTS TO DATE

The development of the decision-making model for the selection of fuel treatment alternatives is dependent upon the completion of three major tasks as illustrated by figure 2:

1. Development of fuel treatment production rates, limitations, and operating costs.

2. Development of a scheme to quantify treatment objectives.

3. Development of fuel prediction model.

The relative size of each task is illustrated in figure 2 by the size of the circles, and the approximate amount of each task that has been completed is shown by shading.

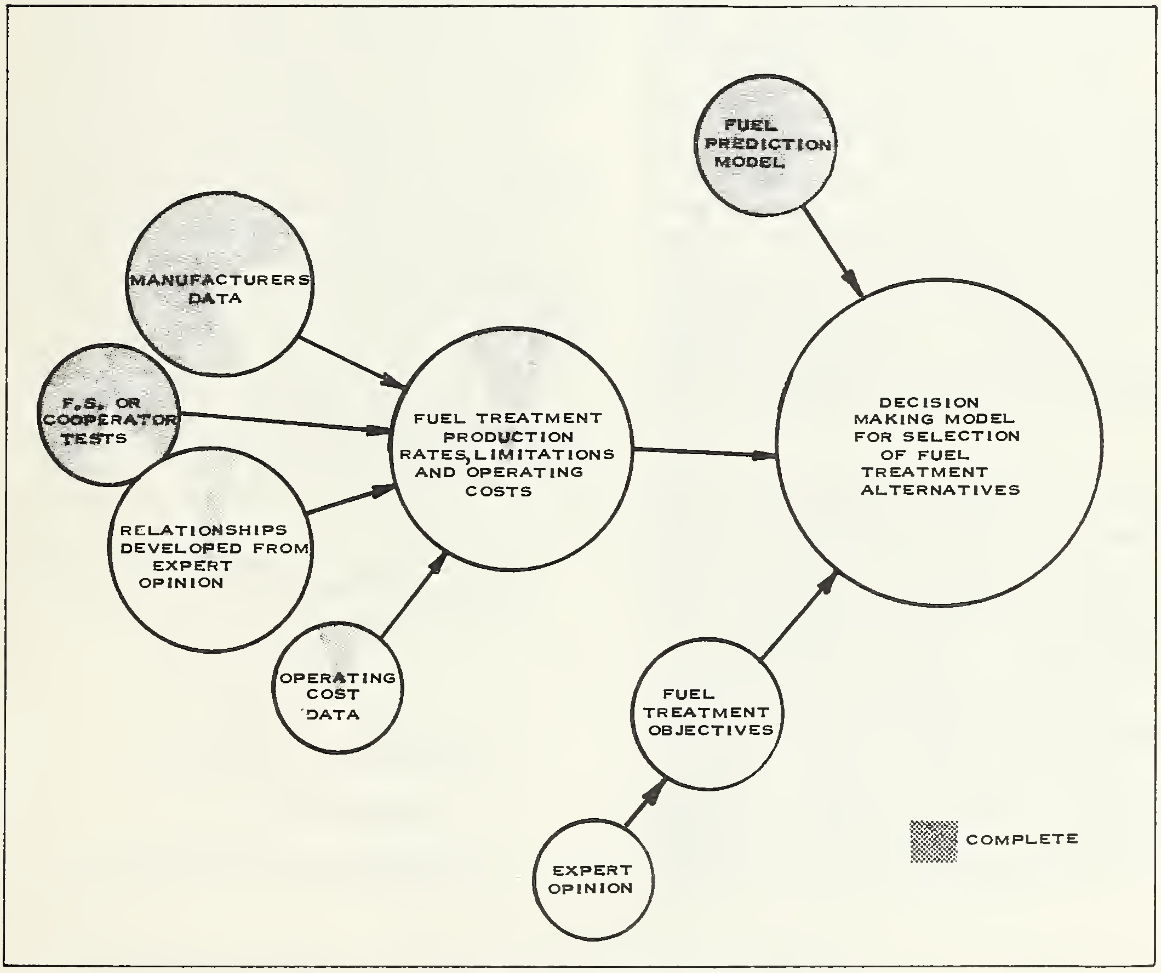


Figure 2.--Major tasks.

Fuel Prediction Model

As shown by figure 2, the fuel prediction model has been completed. The model consists of a user-oriented computer program that uses existing knowledge and data that is commonly available on Forest Service sales in Region 1. The model utilizes sale cruise data, Stage II inventory data and certain information provided by the user.

The linear regressions developed by Fahnestock for Region 1 tree species are used to estimate crown weights.[3/] These equations take into consideration species, d.b.h., and crown length to estimate crown weight. In addition, equations developed by Turnbull and Hoyer to calculate tree volumes by utilizing tariff numbers are used.[4/] Briefly, the tariff number system is another way of expressing tree form. The tariff number is simply the cubic-foot volume of a tree with 1 square foot of basal area. So the higher the tariff number, the better the form of the tree. The tariff number system of computing volume was used because the authors have developed equations to calculate cubic-foot volumes in terms of total tree, excluding the stump, and also volumes to a 4-, 6-, and 8-inch top. Therefore, one can readily estimate the volume in the unutilized top stem based on the merchantability standard of the sale by taking the difference between the total tree volume and the volume to a specified top size.

Four major sources of slash are considered in the fuel prediction model:

1. Harvested trees

    a. Crowns

    b. Unutilized top stems

    c. Cull and breakage

2. Snags that are cut and not utilized.

3. Trees unmerchantable because of size that are damaged by logging.

    a. Crowns

    b. Boles

4. Existing fuels prior to harvesting.

Figure 3 is a flow chart which illustrates the logical sequences that are involved in the fuel prediction model. The program is now in the Region 1 computer library and is available to field units. Appendix A is a set of instructions, which has been distributed to all Region 1 field units, that explains the use of the fuel prediction model. Several field units have used the program and others plan to use it in the near future. The purpose of the fuel prediction model is to provide a "ballpark" estimate of resulting fuels prior to actual harvesting. The accuracy of the predictions is not known at this time; however, the model incorporates the best information that is presently available for fuel prediction. As better information becomes available through research, the model can easily be updated and improved. The reasonableness of the fuel predictions of the model will be determined by the experience of field personnel using the program.

In the instructions (appendix A) is a computer printout of a "run" using cruise data and Stage II inventory data from the Bear Run Timber Sale on the Missoula Ranger District, Lolo National Forest. In this particular case, the predicted fuel loading was within 10 percent of what was actually measured on the ground after harvesting had been completed. The planar intersect method as described by Brown was used to measure the fuel loading.[5/] As one can see, the program requires a significant amount of input from the user but in doing so is very flexible. A sensitivity analysis can be achieved by varying such things as:

3/ Fahnestock, George R. Logging slash flammability. Int. For. and Range Exp. Sta., Res. Paper No. 58, pp. 26-33, May 1960.

4/ Turnbull, K. J. and G. E. Hoyer. Construction and analysis of comprehensive tree-volume tariff tables, Resource Mgt. Rpt. No. 8, State of Washington, Dept. of Natural Resources, p. 56, Aug. 1965.

5/ Brown, James K. A planar intersect method for sampling fuel volume and surface area. Forest Science 17(1): 96-102, 1971.

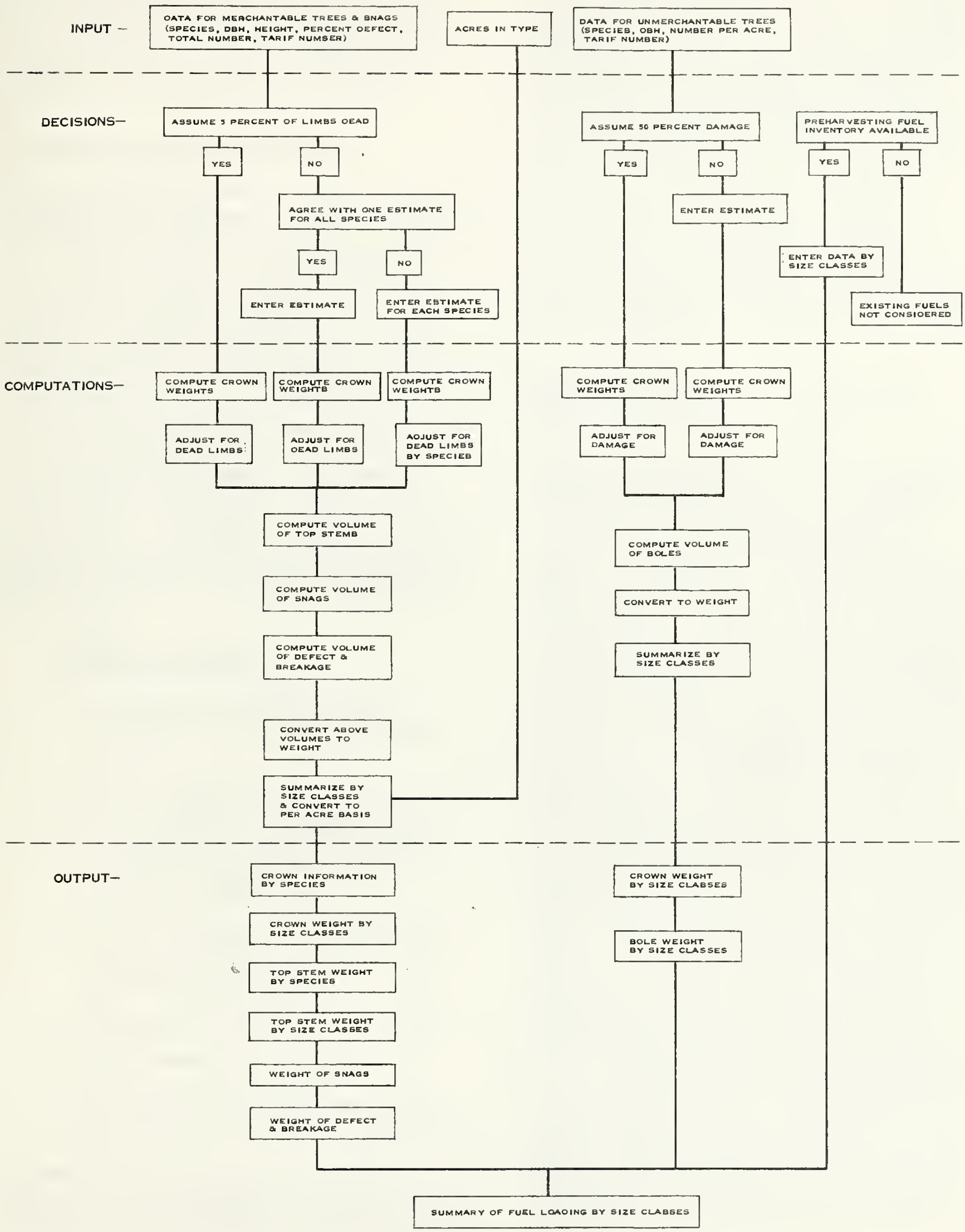


Figure 3.--Computational diagram of fuel prediction model.

percentage estimates of cull and breakage of harvested trees; number, size, and species of trees harvested; percentage estimate of trees unmerchantable because of size damaged by logging and so on.

Quantify Treatment Objectives

As depicted by figure 2, no work has been completed in devising a scheme to quantify fuel treatment objectives. However, it is expected that slash treatment objectives, whether they are for fire hazard reduction, esthetics, site preparation, or whatever, can be expressed quantitatively in terms of fuel loading by size classes. To estimate these fuel loadings, we plan to interview experts in fire control, insect and disease control, wildlife management, reforestation, and landscape management. During the interviews, photographs will be used to illustrate various fuel loadings. Based upon these interviews, a scheme will be devised to quantify various slash treatment objectives. The scheme may appear as follows:

Treatment Objective

1. Esthetics - reduce slash to x tons/ac. with nondisturbance of duff.

2. Fire hazard abatement - reduce to $\leq$ x tons/ac. plus reduce $\leq$ 4-inch size class to $\leq$ y tons/ac. and an average height of slash $\leq$ z feet.

3. Site preparation - reduce slash to $\leq$ x tons/ac. with y percent mineral soil exposed.

4. Wildlife - reduce to x tons/ac. and remove all barriers.

5. Other (e.g., Insect and Disease Control) - reduce to $\leq$ x tons/ac.

It may turn out that the final model will present the land manager with a range of values for each objective and require him to select the value which is appropriate for his particular situation. Whatever technique is devised to quantify treatment objectives, it will not be perfect. However, as land managers become more familiar with fuel loadings, the technique can easily be revised. The important point is that the decision-maker is required to think of his objectives in a quantitative sense and an attempt will be made to help him accomplish this. Refinement of a technique to quantify fuel treatment objectives would appear to be a worthwhile future research project by one of the Forest Service experiment stations.

Production Rates, Limitations, and Operating Costs

The first step in this part of the project involved identifying the treatment methods to be considered. Appendix B illustrates those treatment methods which will probably be considered. In regard to production rates, we hope to develop relationships similar to those illustrated by figure 4 for all treatment methods. Figure 4 is a hypothetical situation showing a linear relationship, based on a regression analysis, between production rates in acres/day and slope for various fuel loadings. Refer to appendix C for a complete discussion of the statistical analysis which was done with hypothetical data to develop the prediction equation shown in figure 4. It is recognized that there are a large number of variables which may influence production rates. However, we plan to consider only those variables which appear to be most significant and can be readily identified such as fuel loading and slope. Other variables such as residual spacing, operator efficiency, number and height of stumps, soils, etc., will be accounted for by making assumptions in the production schedules that are developed. The production rates can then be adjusted up or down when sale conditions are significantly different from the conditions assumed. Guidelines for making these adjustments will be developed.

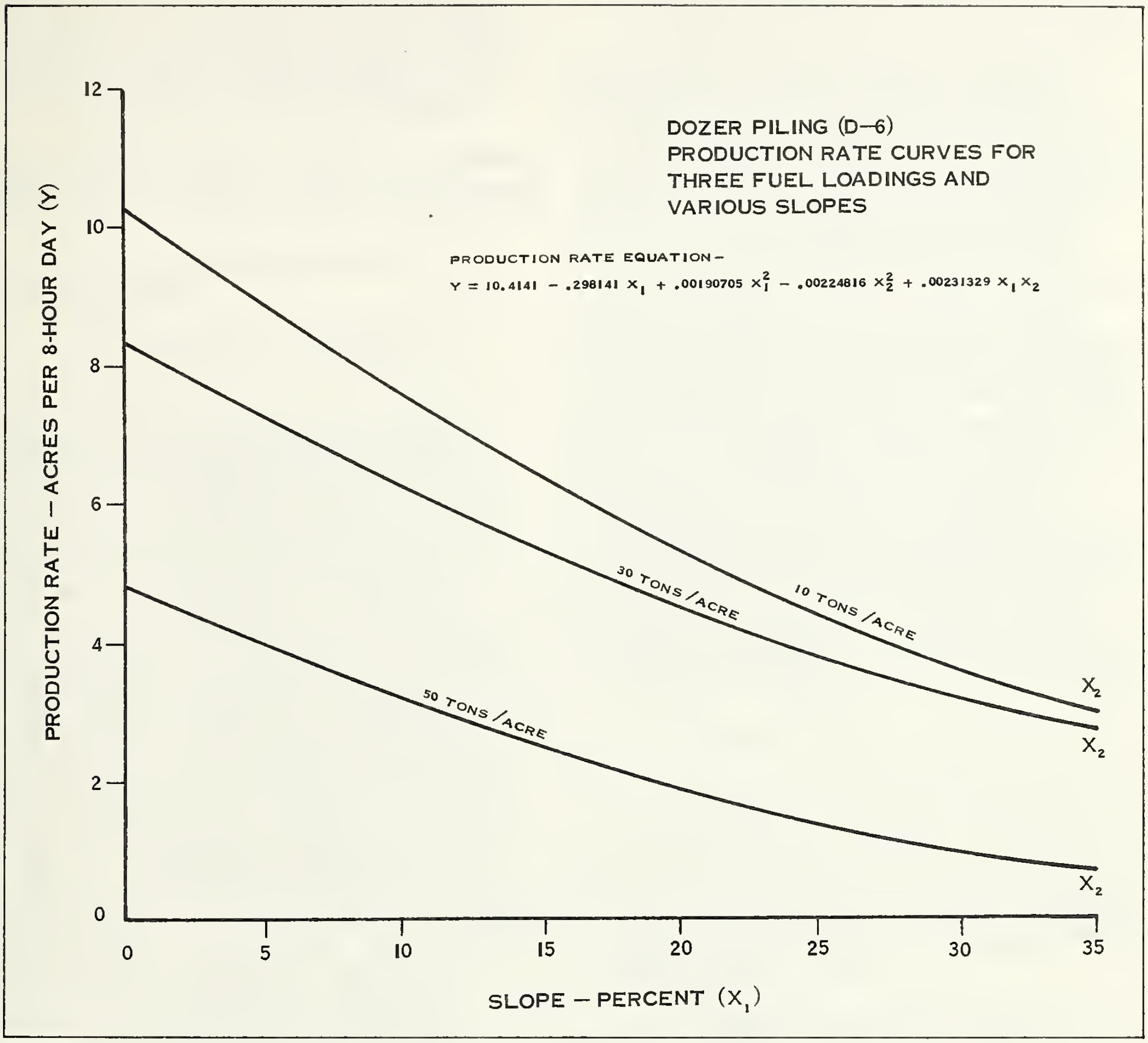


Figure 4.--Hypothetical production rates.

Production rate data and limitations of various slash treatment equipment have been obtained from manufacturers and past studies by the Forest Service and others. In general, the production rate data are not very informative primarily due to variations in working conditions, operator efficiency, and accounting practices. Much of the data will not be very useful in developing a slash treatment model. Therefore, the bulk of the data needed for the development of production rates will be generated through the use of expert opinion. It would be impossible to generate the necessary data through controlled time and motion studies within the time frame of the project. Furthermore, it is doubtful whether all the variables influencing production rates could be integrated with time and motion studies. Therefore, it appears that the use of expert opinion is logical.

Expert opinion will be sought from not only the Forest Service but also companies and contractors in the region. Criteria will be developed for selecting experts for each treatment method. The following factors will be considered:

1. Total experience with a treatment method (acres treated, number of jobs and years).

2. Also, experience under various sale conditions.

3. Willingness to cooperate; sincerity.

Since most field personnel are not familiar with fuel loadings, a series of 8 x 10 color photographs from the National Fuel Inventory and Classification System illustrating various sale conditions and fuel loadings will be utilized in an attempt to supplement this lack of experience. Basically, each expert will be asked to estimate the production rate for a particular treatment method under various sale conditions. It is anticipated that the production rate estimates obtained from various experts for a particular fuel treatment method and a particular fuel loading class and slope will not be the same. Therefore, it may be necessary in some cases to attempt to reduce this variation. The Delphi Method will be utilized to achieve the reduction in variation. Briefly, the Delphi Method consists of initially soliciting estimates from a group of experts on an individual basis while maintaining anonymity. Then certain information such as the median, range of estimates and the individual's estimate is fed back to the participant and he is asked if he desires to revise his previous estimate. Each round or iteration tends to draw the estimates closer together.

In addition to seeking an estimate of production rates for various conditions, each expert will be asked to estimate the effect other variables such as rocks, soil, residual spacing, etc. would have on his original estimate in terms of a percentage increase or decrease. Finally, once data has been obtained, we plan to use regression and correlation analysis to explore the relationship of production rates and various sale conditions. Hopefully, relationships similar to those illustrated by figure 4 can be determined.

In February 1974 the Colville Ranger District, Colville National Forest, was visited to discuss the feasibility of utilizing expert opinion to develop production rates. Cliff Lehman, forestry technician on the District, has been working with tomahawks to treat slash since the early 1960's and has had considerable experience with dozer piling. To get a better feel for some of the possible problems that one may encounter in soliciting production rate estimates from experts, we used Mr. Lehman to make a test run for dozer piling and tomahawking. Two variables were considered directly: slope and fuel loading. Photographs were used to illustrate various fuel loadings. Other important variables were considered indirectly by stating some basic assumptions and then revising the estimate if these assumptions were not met. The basic assumptions for both dozer piling and tomahawking were as follows:

1. Assume the soil to be firm and dry.

2. Assume the spacing of residuals to be approximately 20 feet by 20 feet.

3. Assume brush to be approximately equivalent in density to a Douglas-fir/ninebark habitat type.

4. Assume stump heights are 12 inches or less.

5. Assume there are approximately 25 stumps per acre.

6. Assume average efficiency of a contractor operator.

7. Assume an 8-hour production day.

In reference to dozer piling, two more assumptions were made:

1. Assume that approximately 75 percent of the fuel will be piled, leaving 25 percent unpiled.

2. Assume that approximately 25 percent of the mineral soil will be exposed (scarified).

The production rate estimates for various slopes and fuel loadings provided by Mr. Lehman are illustrated by figure 5. In general, if one or more of the basic assumptions are not met for a specific sale area, the production rates shown in figure 5 should be adjusted accordingly.

For slopes up to 29 percent:

1. If conditions are worse than the basic assumptions, decrease estimate up to 30 percent for the < 20 tons/acre fuel loading class and up to 25 percent for other fuel loading classes depending upon the severity of the deviation from the basic assumption.

2. If conditions are more favorable for production than the basic assumptions, increase the production estimate up to 10 percent for all fuel loading classes.

For slopes 30 percent and greater:

1. For poor conditions, decrease up to 20 percent.

2. For favorable conditions, increase up to 28 percent.

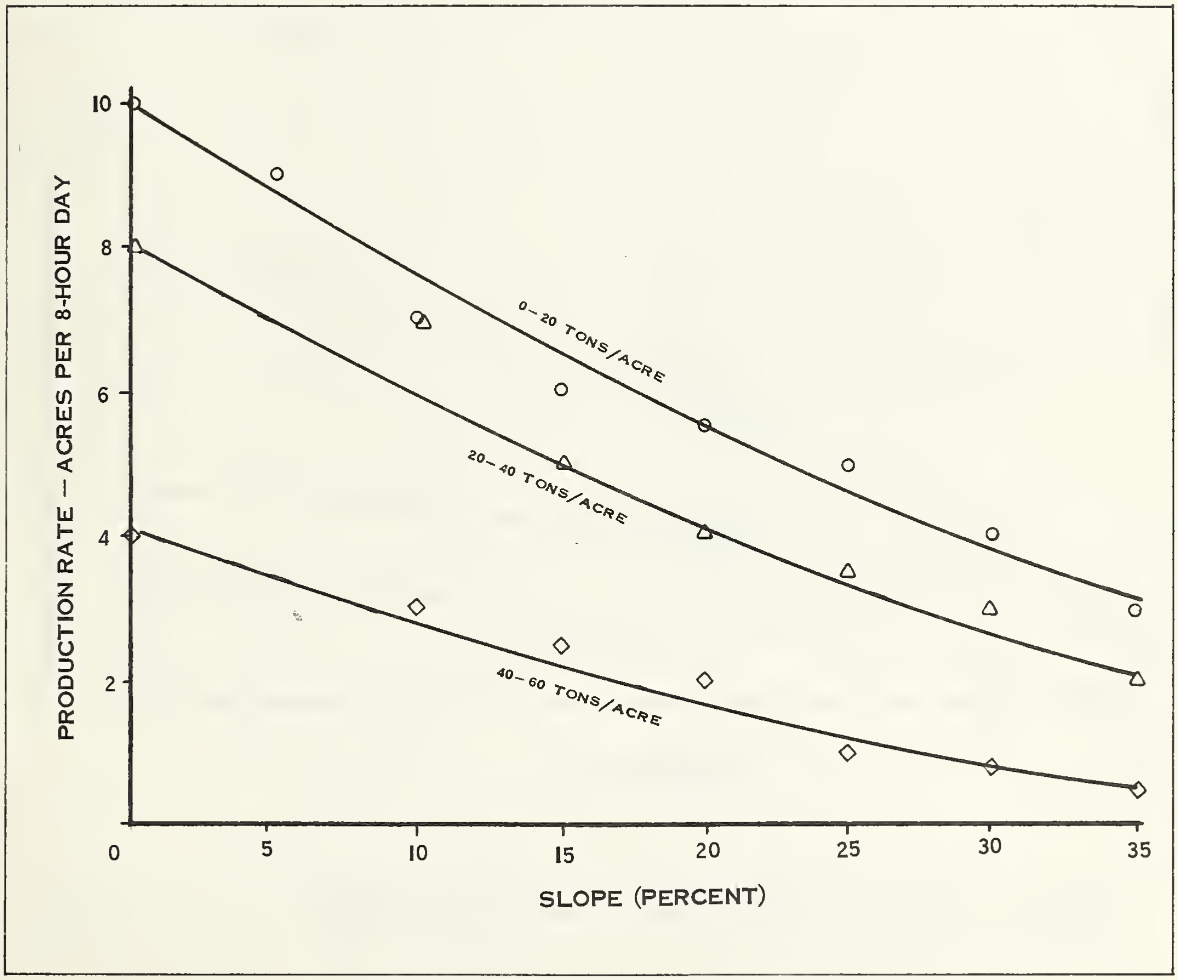


Figure 5.--Dozer piling (medium-size D-6).

In addition, the estimated production rates should be adjusted as follows:

1. Reduce production rates approximately 25 percent if the majority of the fuel consists of full-length small trees that were damaged by logging. This type of fuel is more difficult to pile than normal logging slash.

2. Reduce production rates approximately 5 percent for each road segment on slopes of 20 percent or greater in the area to be treated.

In reference to tomahawking, the same seven basic assumptions were made. Production rate estimates for a 3-foot, single tomahawk mounted on a J.D.-450 or equivalent are illustrated by figure 6. The estimates should be decreased for conditions worse than assumed by up to 30 percent. Also, the presence of rocks or rock barriers would cause a decrease in production rates. Stump heights greater than 12 inches would also cause a decrease. If the slash is arranged in concentrations, a decrease should be made since the slash will need to be spread before treating. The production rate estimates should be increased up to 10 percent for conditions more favorable than those assumed. A 6-inch stump height is most desirable for tomahawking, and the Colville Ranger District has begun to require this in their timber sale contracts for areas that will subsequently be treated with the tomahawk.

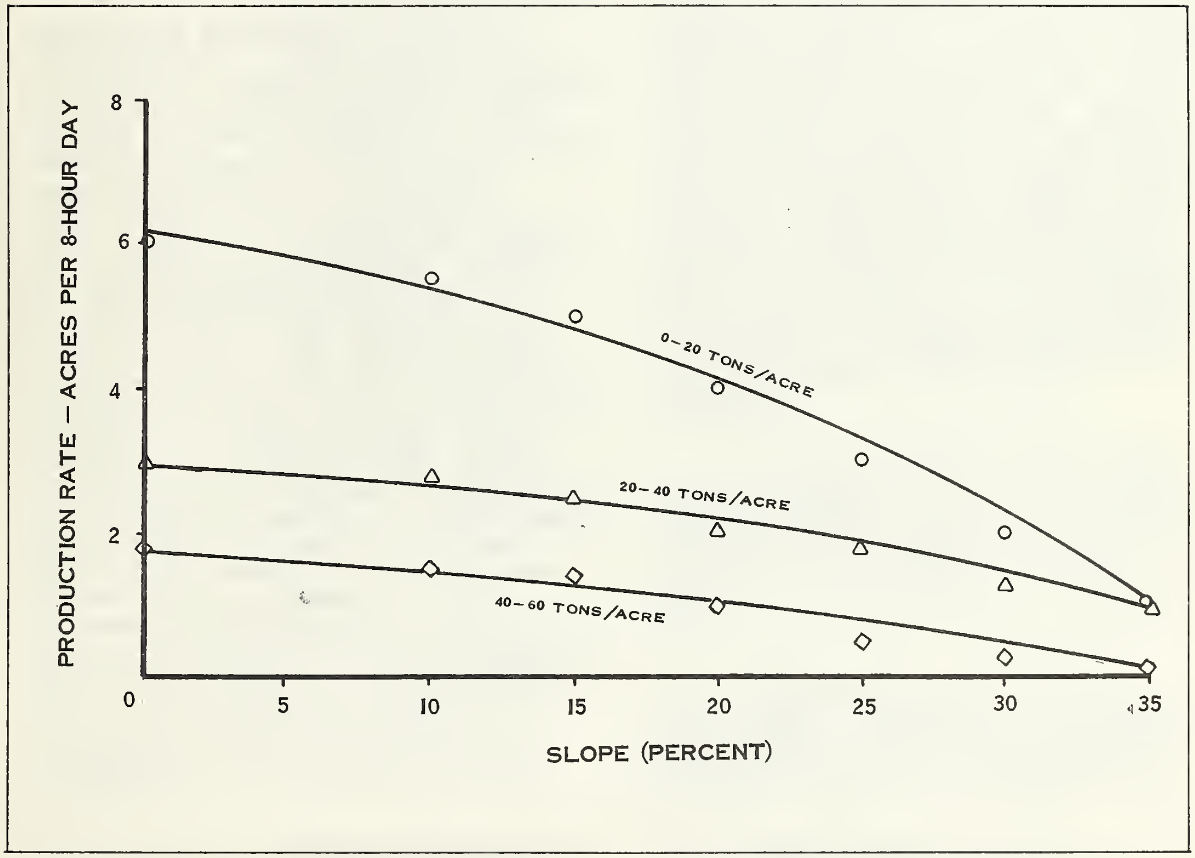


Figure 6.--Tomahawk (3-foot single).

In reference to the limitations of dozer piling and tomahawking in partial cuts, Mr. Lehman stated that the 40 to 60 tons/acre fuel loading class was a maximum. Fuel loadings beyond this range should be considered infeasible since the production rates would be so low. Maximum slopes for dozer piling are approximately 35 percent and are approximately 40 percent for tomahawking and would involve an uphill deadhead trip. Maximum slope which would facilitate both up and down passes for tomahawking is 25 percent. Finally, tomahawking is not very feasible on material larger than 4 inches in diameter.

One problem anticipated in soliciting production rate estimates from experts in regard to various slopes and fuel loadings is the general lack of knowledge or familiarity with fuel loadings. Most experts are accustomed to thinking of fuel in terms of rate of spread and resistance to control which means different things to different people. Fuel loading in terms of tons/acre by various fuel size classes is a more precise means of describing fuels, but few people have had much experience in this area. Therefore, to bridge this general lack of knowledge, photographs of various fuel loadings were used when production rate estimates were solicited from Mr. Lehman. Even though the photographs were not of the size and quality we plan to use when actually interviewing experts, it is surprising how well the photographs appeared to bridge the gap. After viewing a photograph illustrating a particular fuel loading, Mr. Lehman would immediately recall one or more timber sales which looked similar to the photo before receiving treatment. This increased our confidence in the use of photos to supplement the general lack of knowledge of fuel loadings. Based upon this trial run with Mr. Lehman, it appears that obtaining production rate estimates by utilizing expert opinion is feasible.

Operating costs regarding the use of a particular piece of equipment can be developed by considering the cost of leasing or the cost of owning. The cost of leasing when available is a much simpler cost to obtain and will be used. It should accurately reflect the true cost of using the equipment. Finally, standard labor costs including fringe benefits, average overhead costs and normal profits will be used in developing operating costs for a particular treatment method. The final decision-making model will be constructed so operating costs can be adjusted to meet local conditions.

CONCLUSIONS

1. Our problem analysis indicated that most land managers have no reliable or accurate method to predict fuel residues resulting from a particular partial cut sale prior to harvesting. No method exists for quantitatively specifying fuel treatment objectives to determine feasible fuel treatment methods. And, techniques are not available to estimate the associated costs of a particular fuel treatment for a particular set of sale conditions. Therefore, the goal of the project is to develop a decision-making model to predict fuel loadings, fuel treatment needs, treatment alternatives and associated costs prior to harvesting for a specific set of sale conditions. The exact format of the model has not been determined but may consist of a computer program or an algorithm utilizing charts and a calculator.

2. The fuel prediction model which has been completed appears to provide a reasonable method to visualize resulting fuels prior to harvesting. Accuracy of the model will be determined by the experience of field personnel using the tool.

3. Accurate data for developing fuel treatment production rate schedules which consider significant variables are not available even for the most common treatments and must be obtained.

4. A test on the Colville Ranger District indicated that the use of expert opinion to generate production rate data is feasible.

RECOMMENDATIONS

1. Continue the project through fiscal year 1975.

2. Develop fuel treatment production rate schedules and a scheme to quantify fuel treatment objectives to be used in the final decision-making model by utilizing expert opinion.

3. Monitor field use of fuel prediction model and provide technical assistance.

4. Forest Service research should consider a project to develop techniques for quantifying fuel treatment objectives.

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

Region 1, Missoula, Montana 59801

April 19, 1974

REPLY TO: 5150

SUBJECT: Interim Instructions for Use of Fuel Prediction Model

TO: Forest Supervisors

Attached are Interim Instructions for Use of Fuel Prediction Model. This program was developed by Don Weatherhead at MEDC.

This is a program that can be used from a forest computer terminal and should help materially in making better slash predictions. As stated in the introduction to the program, this model uses the best information available and as better or more information is developed it will be updated.

The model isn't difficult to use, but if problems arise in your program, instructions on who to call are already in the computer. This program has had limited testing and accuracy is unknown, but we hope you will give it a try and report back your results.

This is a long needed tool and we have hopes that this, along with other forthcoming information will help you get on top of the slash job. Copies are punched for insertion in the Fuel Management Binder.

William R. Moore

WILLIAM R. MOORE, Chief
Division of Fire Management

cc: Districts

Attachment

INTERIM INSTRUCTIONS FOR USE OF FUEL PREDICTION MODEL

By DONALD J. WEATHERHEAD

April 18, 1974

The Missoula Equipment Development Center (MEDC) is currently working on a project involving fuels management on partial cuts. The name of the project is ED&T 2423 - Fuel Treatment Systems for Partially Cut Stands. The overall objective of the project is to develop a decision-making tool to be used by men in the field to select desirable fuel treatment systems in partial cuts prior to harvesting based on the specific conditions of the sale. A Project Record will be available after July 1974 which will explain the project in detail. One aspect of the decision-making tool depends on the ability of field personnel to predict fuel loading resulting from harvesting in terms of tons per acre by size classes. Therefore, MEDC explored the feasibility of developing a fuel prediction model based on presently known relationships and utilizing readily available information. As a result, a fuel prediction model relative to Region 1 has been developed in the form of a user-oriented computer program. The computer program is designed to be operated by a user at a remote computer terminal. The program requests certain information which is supplied by the user and then provides a predicted fuel loading in terms of tons per acre by size classes. The relative accuracy of the predictions is unknown; however, the program is based upon the best knowledge available regarding fuel prediction. As better knowledge becomes available through research, the model can easily be updated. The Center is very much interested in the experiences field personnel have in the use of the model regarding the relative accuracy of predictions and other comments they may have.

The fuel prediction model considers slash creation from six sources:

1. Crowns of harvested trees.

2. Unutilized portion of the top stem of harvested trees.

3. Estimated defect and breakage that will be left as slash.

4. Snags that are cut and not utilized.

5. Small unmerchantable trees damaged by logging which are left as slash. This includes:

a. Crowns

b. Boles

6. Existing fuels prior to harvesting if known.

Crown weights of harvested trees and small trees damaged by logging are computed by using Fahnestock's equations for tree species found in Region 1.[1/] Tarif volume equations are used to calculate cubic-foot volumes of top stems, defect and breakage, snags and boles of small unmerchantable trees damaged by logging. The cubic-foot volumes are then converted to weight by considering the relative specific gravity of each species.

Information needed to use the fuel prediction model can be obtained from the sale cruise and Stage II inventory. The model has been designed to be used for estimating fuels from partial cutting but can also be used for clearcuts. It is recommended that fuel predictions be made by timber types or cutting units in partial cuts. The information needed and its source is as follows:

1. Number of acres in timber type

2. Including snags as one species, the number of species to be harvested.

3. For harvested trees by species: Sale Cruise

   a. Average DBH

   b. Average height

   c. Total number of trees harvested in timber type.

4. For trees unmerchantable because of size:

   a. Number of diameter classes in timber type (Consider all trees in a diameter class as one species.)

   b. By species: Stage II

      (1) Average DBH

      (2) Number of trees per year

1/ Fahnestock, George R., Logging Slash Flammability. Intermountain Forest and Range Experiment Station, Research Paper No. 58, pp. 26-33, May 1960.

5. Other information needed:

a. Estimate of defect and breakage left as slash.	Based on user's estimate
b. Estimate of percentage of trees unmerchantable because of size that are expected to be damaged by logging and left as slash.	
c. Size of minimum merchantable top of harvested trees.	Timber Sale Contract
d. Fuel loading prior to harvesting.	Preharvesting Fuel Inventory if available.
e. Tarif number by species	Determined by user

Tarif numbers have been mentioned in the preceding discussion with no explanation of them.[2/] Briefly, a tarif number is simply the cubic-foot volume of a tree with one square foot of basal area. For example, a tarif number of 27 means that a tree with one square foot of basal area (approximately 13.5" DBH) will have a volume of 27 cubic-feet. Therefore, the larger the tarif number, the more volume found in a tree. So the tarif number is really another way of expressing the form of a tree. Tarif numbers are used in the fuel prediction model because cubic-foot volume can easily be computed using equations for the entire tree including the top and volume to a 4-, 6-, and 8-inch top. Therefore, it is simple to estimate the volume in the unutilized portion of the top stem in harvested trees. For example, if the minimum top DIB is 6 inches, one can determine the volume in the entire tree including the top and then determine the volume to a 6-inch top. The difference between the two volume calculations is the volume in the unutilized top stem.

Tarif numbers can be determined by using a computer program called *TARIF which is stored in the CSC computer in Los Angeles. Region 1 users have access to this computer facility. Exhibit 1 is a photocopy of a printout of a "run". As with the fuel prediction model, this program also depends on user supplied information. Tarif numbers should be determined for each species by timber type. As noted in Exhibit 1, the program requests the average DBH and average height by species and then the

---

2/ Turnbull, K.J. and G.E. Hoyer, Construction and Analysis of Comprehensive Tree-Volume Tarif Tables, Resource Management Report No. 8, State of Washington, Dept. of Natural Resources, p. 64, April 1965.

tarif number is computed. The program is designed to accept DBH's to the nearest one-inch class for diameters 5-10 inches and the nearest even two-inch class for larger diameters.

Once tarif numbers and other information have been obtained, the user can make a fuel prediction. The fuel prediction model is called *FUEL and is also stored at the CSC computer center. Exhibit 2 is a photocopy of a "run" using data from the Bear Run Timber Sale on the Missoula Ranger District. Referring to Exhibit 2, the first half or more of the program consists of instructions and questions to obtain information. The last line of the program gives the predicted fuel loading by size classes. Results of preceding computations of various fuel components are also printed out prior to the final fuel loading estimate. These results may be of value to some users. Also, it should be noted that the program is designed to be very flexible and a sensitivity analysis can easily be accomplished. For example, one can explore the effect upon fuel loading by varying such things as:

1. Percentage estimate of trees unmerchantable because of size damaged by logging.

2. Size and number of harvested trees.

3. Minimum top size.

4. Snags (number cut and not utilized).

5. Estimated defect and breakage left as slash.

As mentioned earlier, MEDC is interested in the experiences of field personnel using the fuel prediction model and would appreciate their opinion regarding the accuracy and usefulness of the model. Finally, it should be restated that the model is an attempt to utilize existing knowledge and readily available information to predict fuel loading. The accuracy of the model is unknown. The total fuel loading estimate may be reasonably accurate as well as the 4-inch and greater size class. However, the breakdown of size classes less than 4 inches is based on a minimal amount of data.

EXHIBIT 1

SAMPLE "RUN" OF TARIF PROGRAM

```
RUN

*TARIF    12:57    04/12/74

THIS PROGRAM DETERMINES THE APPROPRIATE TARIF NUMBER FOR EACH
TREE SPECIES TO USE WITH THE FUEL PREDICTION MODEL.  YOU
SHOULD DETERMINE TARIF NUMBERS BY TIMBER TYPES FOR EACH SPECIES.
THEREFORE, MAKE SEPARATE 'RUNS' WITH THIS PROGRAM FOR EACH
TIMBER TYPE.

SPECIES:                                     CODE
WESTERN WHITE PINE                             1
WESTERN REDCEDAR                               2
WESTERN HEMLOCK                                3
ENGELMANN SPRUCE                               4
GRAND FIR                                      5
SUBALPINE FIR                                  6
LODGEPOLE PINE                                 7
PONDEROSA PINE                                 8
DOUGLAS-FIR                                    9
WESTERN LARCH                                 10

HOW MANY SPECIES DO YOU WANT TARIF NUMBERS FOR IN THIS TIMBER
TYPE?
?5

TO DETERMINE TARIF NUMBERS BY SPECIES FOR THIS TIMBER TYPE,
USE THE ABOVE NUMERICAL CODES FOR SPECIES AND TYPE IN THE
FOLLOWING DATA (SEPARATE EACH DATA ENTRY WITH A COMMA):
SPECIES, AVE DBH AND AVE HEIGHT.
?6,12,68,10,26,100,7,10,58,8,16,56,9,16,66

   AVE AVE TAR
SP DBH HT   NO
 6  12  68  27
 10  26  100  28
 7  10  58  29
 8  16  56  19.5
 9  16  66  21.5
NOW AT 172
SRU'S:0.3
READY
```

EXHIBIT 2

SAMPLE "RUN" OF FUEL PREDICTION MODEL

```
RUN

*FUEL    13:00    04/12/74

THIS PROGRAM PREDICTS FUEL LOADING RESULTING FROM PARTIAL
CUTTING FOR EACH TIMBER TYPE IN YOUR SALE.  THE PREDICTION
IS BASED UPON CRUISE AND STAGE II DATA WHICH IS SUPPLIED
BY THE USER.

WHEN DATA IS REQUESTED, USE THE FOLLOWING NUMERICAL CODES FOR
TREE SPECIES:


SPECIES:                                    CODE
WESTERN WHITE PINE                             1
WESTERN REDCEDAR                               2
WESTERN HEMLOCK                                3
ENGELMANN SPRUCE                               4
GRAND FIR                                      5
SUBALPINE FIR                                  6
LODGEPOLE PINE                                 7
PONDEROSA PINE                                 8
DOUGLAS-FIR                                    9
WESTERN LARCH                                 10
SNAGS                                         11

INCLUDING SNAGS AS ONE SPECIES, HOW MANY COMMERCIAL SPECIES
ARE THERE IN THIS TIMBER TYPE?
?6
USING THE ABOVE NUMERICAL CODES, TYPE IN THE FOLLOWING DATA
FOR EACH SPECIES (SEPARATE EACH DATA ENTRY WITH A COMMA):
SPECIES, AVE DBH, AVE HEIGHT, % DEFECT, TOTAL TREES PER
SPECIES, AND TARIF NUMBER.  REMEMBER TO ENTER ZERO'S WHERE
APPROPRIATE AND INCLUDE SNAGS.  % DEFECT REFERS TO DEFECT
AND BREAKAGE THAT YOU ESTIMATE WILL BE LEFT AS SLASH FUEL.
?6,12,68,9.8,1160,27,10,26,100,0,26,28,7,10,58,4.6,2647,29
?8,16,56,3.3,832,19.5,9,16,66,9.1,6170,21.5,11,19,78,100,416,28
```

```
                    YOUR DATA CONSISTS OF THE FOLLOWING:


   AVE AVE   %   TOTAL TAR
SP DBH  HT DEF TREES NO
 6   12  68  9.8   1160   27

 10   26   100   0   26   28

 7   10   58   4.6   2647   29

 8   16   56   3.3   832   19.5

 9   16   66   9.1   6170   21.5

 11   19   78   100   416   28


IS THIS DATA CORRECT (YES=1, NO=0)?
?1
GOOD!
HOW MANY ACRES ARE IN THIS TIMBER TYPE?
?166
AS INDICATED ON THE STAGE II INVENTORY, HOW MANY DIAMETER
CLASSES ARE REPRESENTED IN TREES UNMERCHANTABLE BECAUSE
OF SIZE?
?2
NEXT TYPE IN THE FOLLOWING DATA FOR UNMERCHANTABLE TREES
BECAUSE OF SIZE :
SPECIES, DBH, TREES/ACRE, TARIF NO.  USE THE PREVIOUSLY
STATED CODE FOR SPECIES.
YOUR DATA CAN BE OBTAINED FROM THE STAGE II INVENTORY.
ASSUME ALL TREES IN EACH DIAMETER CLASS ARE ONE SPECIES.
?6,2,2040,27,6,4,60,27


YOUR DATA FOR TREES UNMERCHANTABLE BECAUSE OF SIZE IS
AS FOLLOWS:


        TREES  TARIF
SP DBH  /AC      NO
 6  2  2040  27

 6  4  60  27



IS THIS DATA CORRECT (YES=1, NO=0)?
?1
```

```
THERE ARE SEVERAL ASSUMPTIONS MADE IN THIS PROGRAM WHICH
CAN  BE ALTERED IF YOU DISAGREE.  FIRST OF ALL IT IS ASSUMED
THAT APPROXIMATELY 50% OF THE SMALL UNMERCHANTABLE TREES
WILL BE DAMAGED BY LOGGING AND WILL CONTRIBUTE TO THE SLASH
PROBLEM.
DOES THIS APPEAR TO BE A REASONABLE ASSUMPTION (YES=1,
NO=0)?
?0
TYPE IN YOUR PERCENTAGE ESTIMATE.
?25
ANOTHER ASSUMPTION THAT HAS BEEN MADE IS THAT APPROXIMATELY
10% OF THE TOTAL LIMBS ON ALL COMMERCIAL SPECIES ARE DEAD.
DOES THIS APPEAR TO BE REASONABLE (YES=1,NO=0)?
?1

THIS PROGRAM CONSIDERS A MERCHANTABLE TOP DIB OF 4,6 OR 8
INCHES.
TYPE IN THE MERCHANTABLE TOP SIZE FOR THIS SALE THAT IS
NEAREST TO ONE OF THE THREE SIZES ABOVE.
?6


IS THERE A PREHARVESTING FUEL INVENTORY AVAILABLE FOR THIS
TIMBER TYPE (YES=1, NO=0)?
?1
TYPE IN THE FUEL LOADING (TONS/ACRE) FOR THE VARIOUS SIZE
CLASSES IN THE FOLLOWING ORDER:  0- 1/4 INCHES, 1/4 - 1 IN.,
1 - 3 IN., 3+ IN. AND TOTAL.
?2.1,1.5,3.2,4.5,11.3
```

CROWN INFORMATION BY SPECIES

SPECIES	CROWN LENGTH	CROWN WEIGHT	TOTAL WEIGHT
6	44.94	144.927	184926.
10	71.6	346.483	9909.4
7	30.	75.4736	219757.
8	45.6	310.274	283962.
9	45.6	205.574	1.39523E+6

CROWN WEIGHT BY SIZE CLASSES
(TOTAL POUNDS FOR TIMBER TYPE)

0-1/4IN	1/4-1IN	1-4IN	TOTAL
759772.	614942.	719069.	2.09378E+6

```
UNMERCHANTABLE TOP WEIGHTS BY SPECIES
   (TOTAL POUNDS FOR TIMBER TYPE)
SPECIES          TOP WEIGHT
 6                45531.9
 10               1219.1
 7                181087.
 8                14518.
 9                124954.


     WEIGHT OF TOP STEMS
  (TOTAL POUNDS FOR TIMBER TYPE)
<= 4-INCHES      TOTAL
 111732.          367310.


WEIGHT OF SNAGS
(TOTAL POUNDS FOR TIMBER TYPE)
 453182.

WEIGHT FROM DEFECT AND BREAKAGE
(TOTAL POUNDS FOR TIMBER TYPE)
 526971.


SMALL UNMERCHANTABLE TREES DAMAGED BY LOGGING
       CROWN WEIGHT BY SIZE CLASSES
             POUNDS/ACRE

0-1/4IN          1/4-1IN          1-4IN           TOTAL
 3439.23          1492.12          1759.76          6691.11


BOLE WEIGHTS OF TREES DAMAGED BY LOGGING
             POUNDS/ACRE
    <=4-INCHES      TOTAL

     2824.12         2824.12

             FUEL LOADING FOR TIMBER TYPE BY SIZE CLASSES
                            TONS/ACRE
0-1/4IN          1/4-1IN          1-4IN           4+ IN           TOTAL
 6.10808          4.09829          7.99435          8.22208          26.4228
NOW AT 1606
SRU'S:1.6
READY
```

POSSIBLE TREATMENTS TO BE CONSIDERED

A. Dozer Piling

1. light)
2. medium) based on horsepower and weight
3. heavy)

B. Hand Piling

C. Chipping

1. Inplace

a. light)
b. medium) based on size of chipper head and horsepower
c. heavy)

2. Selected sites

a. light
b. medium
c. heavy
d. include skidding or bunching costs
e. include cost of disposal of chips or selling value whichever is appropriate.

D. Tree-length skidding to landing

E. Skidding Tops

F. Masticating Inplace (includes Tomahawk, Morden Chopper, Tree-Eater, etc.)

G. Additional Cost of Using a Feller-Buncher to Concentrate Tops for Skidding or Treatment

H. Dozer Trampling

I. Pit or Incinerator

J. Burying

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
Equipment Development Center
Fort Missoula
Missoula, Montana 59801

REPLY TO: 7120 Equipment Development and Test June 27, 1974

SUBJECT: ED&T 2423 - Fuel Treatment Systems for Partially Cut Stands

TO: A. H. Jukkala, Project Leader

The following is a statistical analysis of hypothetical production rate data. The objective of this analysis is to become familiar with the procedures I intend to use with the real data and also identify any statistical problems that could be avoided when obtaining the data. Exhibit 1 illustrates the type of data that is expected to be obtained for dozer piling slash. The data represents production rates in terms of acres/day that can be treated with a medium size dozer (D6) under various slope and fuel loading combinations. The production rate estimates underscored are actual estimates from an expert I interviewed in February 1974. The other estimates in each slope and fuel loading category represent hypothetical estimates from six other experts.

Figures 1-3 illustrate the data plotted for three fuel loading classes and various slopes ranging from 0% to 35%. Since the plan is to fit a curve to this data using regression analysis, some assumptions must be made. It is assumed that all Y's (production rates) are normally distributed and have the same variance for all values of X (slope and fuel loading). The plotted data on figures 1-3 suggests that possibly the Y's do not have homogeneous variance since the range in production rate estimates is relatively large for small values of slope and fuel loading and decrease as slope and fuel loading increase. Therefore, I attempted to compensate for this possible heterogeneity in variance with a logrithmic transformation of the Y values as illustrated by figure 4. However, as the figure depicts, the possible heterogeneity was reversed with the transformation. This suggested that possibly it was reasonable to assume that the Y's did have homogeneity. In a further effort to determine whether it was reasonable to assume homogeneity, I used Bartlett's test as described by Snedecor.[1/] I wrote a computer program to perform the calculations using Snedecor's data for a test.

[1/] Snedecor, G. W. 1962. Statistical Methods. Chapter 10, pp. 285-287. Iowa State University Press, Ames, Iowa.

The program and output are shown in exhibit 2. I then used the program to calculate a Chi Square for my data for each fuel loading. With each fuel loading I had seven samples (values of slope) with seven observations each (production rate). Exhibits 3-5 show the calculated Chi Squares obtained which range from 1.26 to 3.9. In each case I was testing the hypothesis that the variance of production rate is the same for all values of slope. The null hypothesis is as follows:

$$H_o: \; s_1^2 = s_2^2 = s_3^2 = s_4^2 = s_5^2 = s_6^2 = s_7^2 = \sigma^2.$$

The tabulated value of Chi Square with six degrees of freedom at the 95% confidence level is 12.59. Since all of the calculated Chi Squares are less than 12.59, I could not reject the hypothesis at the 95% confidence level. Therefore, it appears reasonable to assume that the Y's have homogeneous variance.

I used a step-wise multiple regression canned program from Computer Science Corporation in Los Angeles to determine a best fitting equation for the data. The plotted data suggested that a curve may fit better than a straight line. Therefore, I considered the following independent variables:

$$x_1 = \text{slope (\%)}$$

$$x_2 = \text{fuel loading (tons/ac.)}$$

$$x_3 = (x_1)^2$$

$$x_4 = (x_2)^2$$

$$x_5 = (x_1 x_2)$$

I began by considering all of the variables in the regression. The model was as follows:

$$\hat{y} = b_o + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5b_5$$

The computer printout (see exhibit 7) suggested that regression due to x_2 was insignificant; therefore, I tested the hypothesis that $b_2 = 0$ at the 5% significance level using an F-test in an analysis of variance (exhibit 6). The H_o: $b_2 = 0$ could not be rejected at the 5% level. This same conclusion was also arrived at using the calculated t value for b_2 from the computer printout. Therefore, I considered the optimum model to be:

$$\hat{y} = b_o + b_1x_1 + b_3x_3 + b_4x_4 + b_5x_5$$

I then tested the significance of each variable using an F-test (exhibit 6). It turned out that all of the variables were significant at the 5% significance level. The final prediction equation is:

$$\hat{y} = 10.4141 - .298141\ (x_1) + .00190705\ (x_3) - .0024816\ (x_4) + .00231329\ (x_5) \text{ with } R^2 = .753.$$

In other words, the equation explains about 75% of the variation in Y. Or the use of slope and fuel loading in the equation accounts for approximately 75% of the variation in production rates.

Finally, figure 5 illustrates the prediction equation for various values of slope and three levels of fuel loading. It is interesting to note that the interaction of slope and fuel loading is the most significant variable. In addition the relationship of production rate to slope and also to fuel loading is curvilinear. The prediction equation (curved line) was also drawn through the plotted data in exhibits 1-3.

Donald J. Weatherhead

DONALD J. WEATHERHEAD
Forester

FIGURE 1

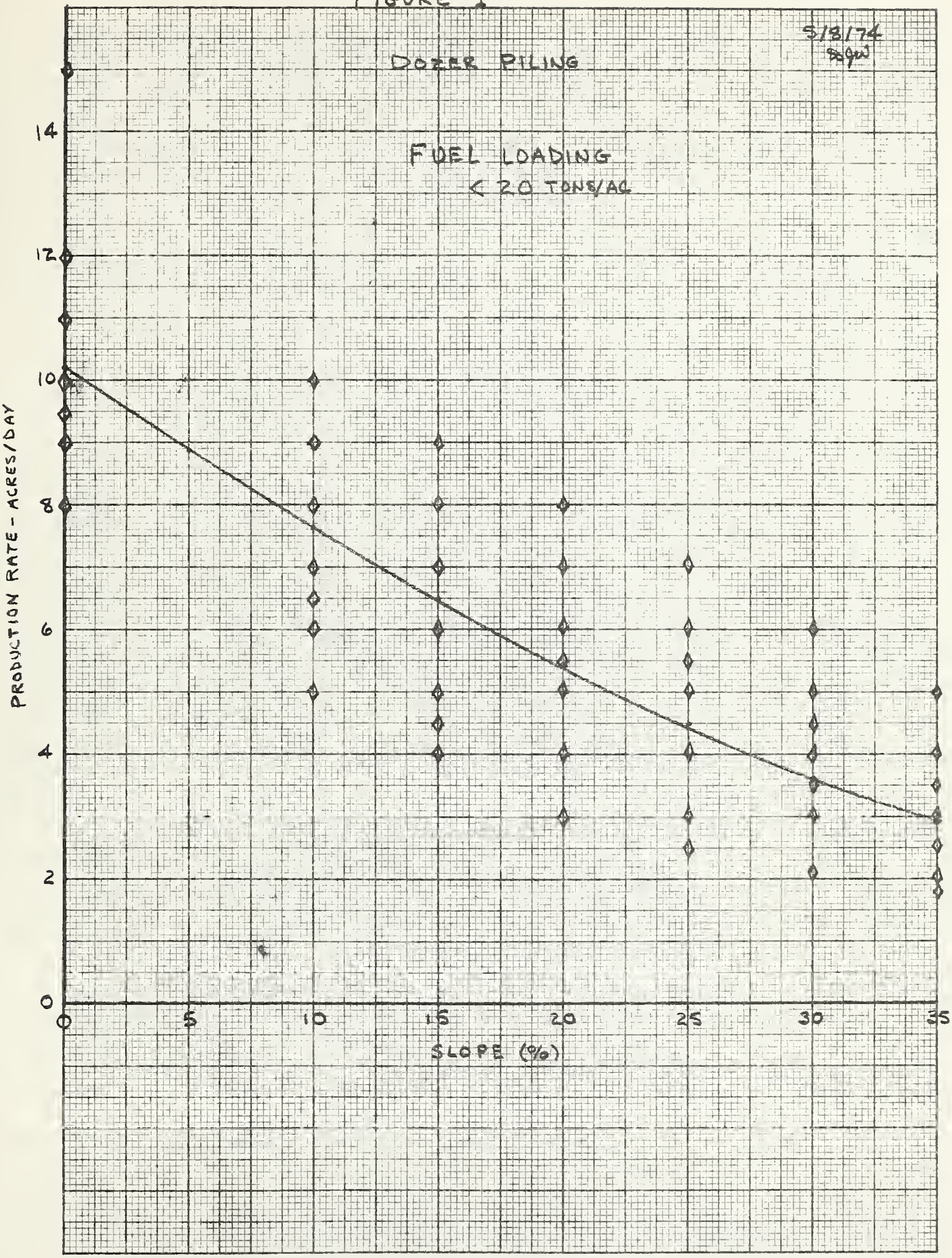
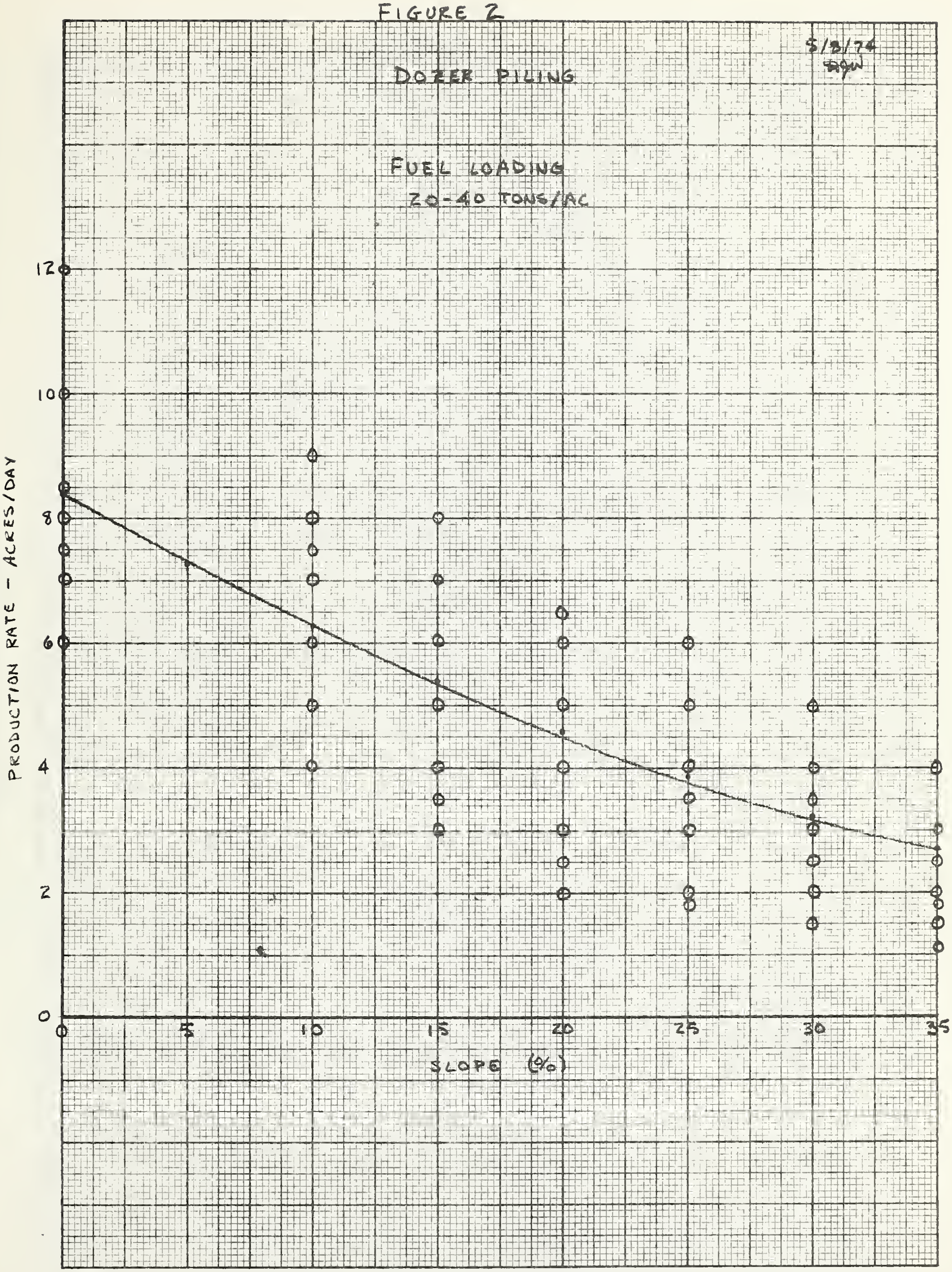

5/8/74
DOZER PILING
FUEL LOADING
< 20 TONS/AC
PRODUCTION RATE - ACRES/DAY
0
2
4
6
8
10
12
14
0
5
10
15
20
25
30
35
SLOPE (%)

FIGURE 2



5/8/74
DOZER PILING
FUEL LOADING
20-40 TONS/AC
PRODUCTION RATE - ACRES/DAY
0
2
4
6
8
10
12
0
5
10
15
20
25
30
35
SLOPE (%)

FIGURE 3

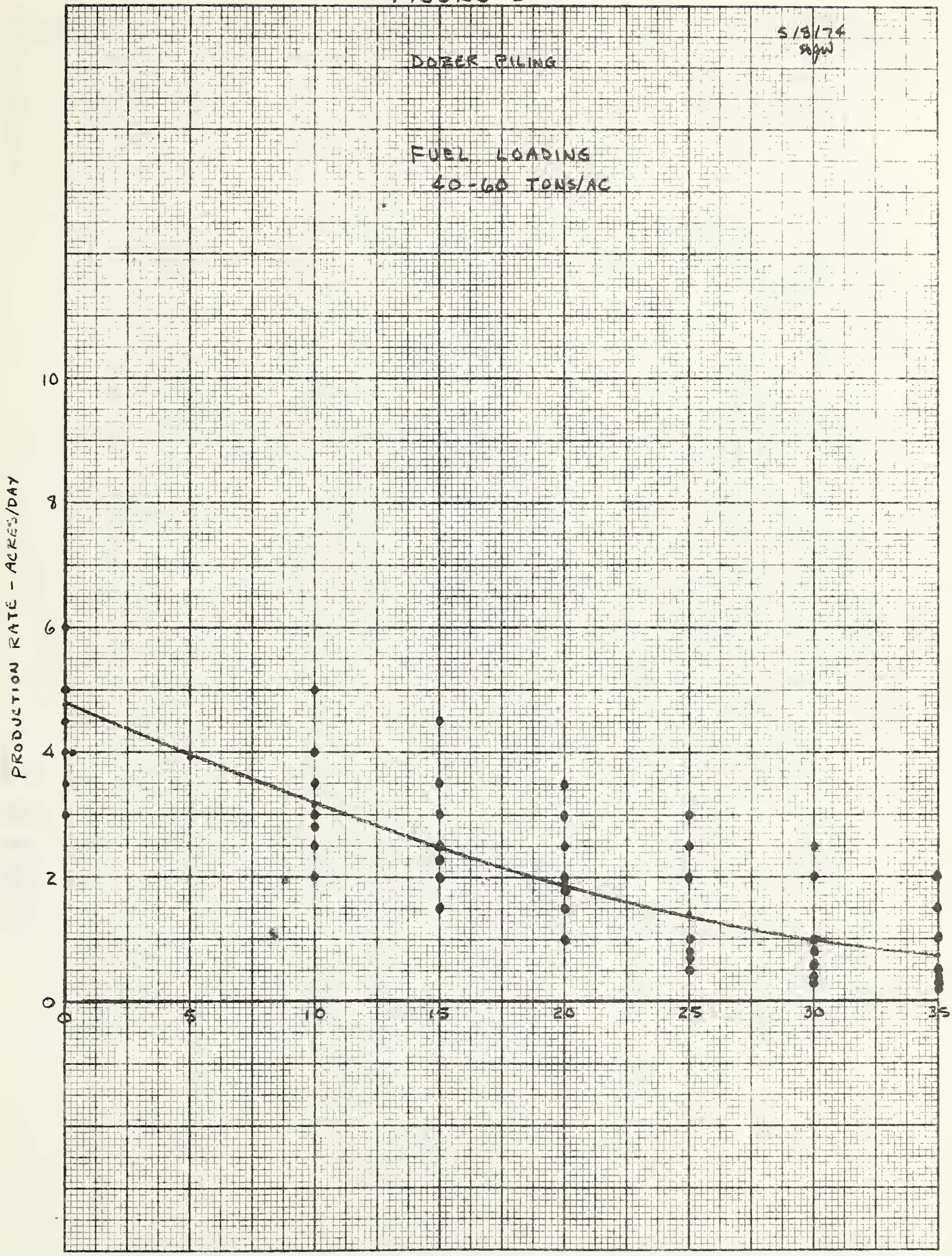

5/8/74
DOZER PILING
FUEL LOADING
40-60 TONS/AC
PRODUCTION RATE - ACRES/DAY
0
2
4
6
8
10
0
5
10
15
20
25
30
35

FIGURE 4

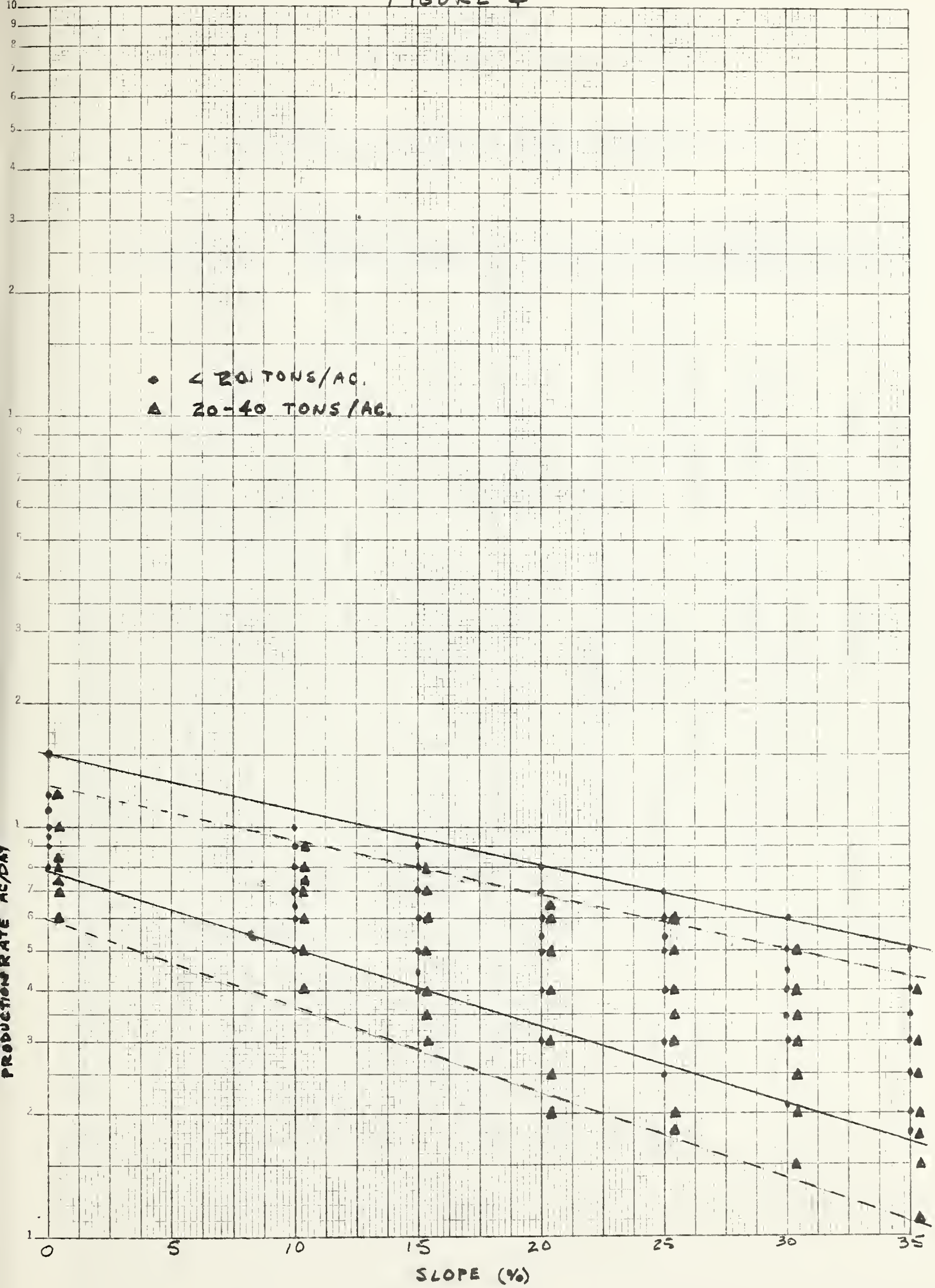


EXHIBIT 1

DOZER PILING - MEDIUM, D6

Estimates of Production Rates (acres/day) by
Slope and Fuel Loading Classes

Slope	Tons/acre <20	Tons/acre 20-40	Tons/acre 40-60	Slope	Tons/acre <20	Tons/acre 20-40	Tons/acre 40-60
0	15 12 11 10 9.5 9 8	12 10 8.5 8 7.5 7 6	6 5 4.5 4 4 3.5 3	25	7 6 5.5 5 4 3 2.5	6 5 4 3.5 3 2 1.8	3 2.5 2 1 .8 .7 .5
10	10 9 8 7 6.5 6 5	9 8 7.5 7 6 5 4	5 4 3.5 3 2.8 2.5 2	30	6 5 4.5 4 3.5 3 2.1	5 4 3.5 3 2.5 2 1.5	2.5 2 1 .8 .6 .4 .3
15	9 8 7 6 5 4.5 4	8 7 6 5 4 3.5 3	4.5 3.5 3 2.5 2.3 2.0 1.5	35	5 4 3.5 3 2.5 2 1.8	4 3 2.5 2 1.8 1.5 1.1	2 1.5 1 .5 .4 .3 .2
20	8 7 6 5.5 5 4 3	6.5 6 5 4 3 2.5 2	3.5 3 2.5 2 1.8 1.5 1				

```
HOMOG1     11:07  ATL TUE    06/18/74

 4 SAMPLES WITH 5 OBSERVATIONS EACH.
SAMPLE          SUM OF SQUARES MEAN SQUARE    LOG OF MEAN SQUARE
 1                472            118            2.07188
 2                396            99             1.99564
 3                616            154            2.18752
 4                164            41             1.61278

MEAN OF S↑2 = 103     LOG OF MEAN S↑2 = 2.01284
DIFFERENCE = .183527
UNCORRECTED CHI SQUARE = 1.69036
DEGREES OF FREEDOM = 3

CORRECTED CHI SQUARE = 1.53089



RUNNING TIME:      .5 SECS    I/O TIME :      .4 SECS

READY
LISTNH
1 REM COMPUTATION OF BARTLETT'S TEST FOR HOMOGENEITY OF VARIANCE.
2 REM SAMPLES EQUAL IN SIZE.  REFER TO SNEDECOR PAGE 286.
3 REM ENTER DATA STARTING WITH LINE 20 - 200.  FIRST ENTER A AND
5 REM N.  A= NUMBER OF SAMPLES, N= NUMBER OF OBSERVATIONS PER
7 REM SAMPLE.  DATA IS ENTERED FOR THE PROBLEM SNEDECOR DISCUSSES.
20 DATA 4,5
30 DATA 40,24,46,20,35
40 DATA 29,27,20,39,45
50 DATA 11,31,17,37,39
60 DATA 17,21,28,33,21
210 READ A,N
215 PRINT A;"SAMPLES WITH";N;"OBSERVATIONS EACH."
218 PRINT"SAMPLE","SUM OF SQUARES","MEAN SQUARE","LOG OF MEAN SQUARE"
220 FOR J = 1 TO A
225 LET X1 = 0
227 LET X2 = 0
230 FOR I = 1 TO N
235 READ X
240 LET X1 = X1 + X
250 LET X2 = X2 + X↑2
260 NEXT I
262 LET X3 = 0
264 LET X4 = 0
266 LET X5 = 0
270 LET X3 = X2 - X1↑2/N
280 LET X4 = X3/(N-1)
290 LET X5 = CLG(X4)
300 LET X6 = X6 + X4
310 LET X7 = X7 + X5
330 PRINT J,X3,X4,X5
340 NEXT J
350 PRINT
355 LET X8 = X6/A
358 LET X9 = CLG(X8)
360 PRINT "MEAN OF S↑2 =";X8"    LOG OF MEAN S↑2 =";X9
370 LET Y = A*X9 - X7
380 PRINT "DIFFERENCE =";Y
390 LET Y1 = 2.3026*(N-1)*Y
400 PRINT "UNCORRECTED CHI SQUARE ="Y1
410 PRINT "DEGREES OF FREEDOM =";A-1
420 LET C = 1 + ((A+1)/(3*A*(N-1)))
430 LET Y2 = Y1/C
440 PRINT
450 PRINT "CORRECTED CHI SQUARE =";Y2
999 END
```

```
20 DATA 7,7
30 DATA 15,12,11,10,9.5,9,8
40 DATA 10,9,8,7,6.5,6,5
50 DATA 9,8,7,6,5,4.5,4
60 DATA 8,7,6,5.5,5,4,3
70 DATA 7,6,5.5,5,4,3,2.5
80 DATA 6,5,4.5,4,3.5,3,2.1
90 DATA 5,4,3.5,3,2.5,2,1.8
RUN
```

EXHIBIT 3
10 TONS / ACRE

```
HOMOG1     11:19   ATL  TUE    06/18/74

 7 SAMPLES WITH 7 OBSERVATIONS EACH.
SAMPLE          SUM OF SQUARES MEAN SQUARE     LOG OF MEAN SQUARE
 1                32.3571         5.39286         .731819
 2                18.3571         3.05952         .485654
 3                20.9286         3.4881          .542588
 4                17.5            2.91667         .464887
 5                15.9286         2.65476         .424026
 6                10.1086         1.68476         .226539
 7                7.84857         1.3081          .116639

MEAN OF S↑2 = 2.92925     LOG OF MEAN S↑2 = .466757
DIFFERENCE = .275145
UNCORRECTED CHI SQUARE = 3.8013
DEGREES OF FREEDOM = 6

CORRECTED CHI SQUARE = 3.57436
```

```
30 DATA 12,10,8.5,8,7.5,7,6
40 DATA 9,8,7.5,7,6,5,4
50 DATA 8,7,6,5,4,3.5,3
60 DATA 6.5,6,5,4,3,2.5,2,
70 DATA 6,5,4,3.5,3,2,1.8
80 DATA 5,4,3.5,3,2.5,2,1.5
90 DATA 4,3,2.5,2,1.8,1.5,1.1
RUN
```

EXHIBIT 4
30 TONS / ACRE

```
HOMOG1     11:25   ATL  TUE    06/18/74

 7 SAMPLES WITH 7 OBSERVATIONS EACH.
SAMPLE          SUM OF SQUARES MEAN SQUARE     LOG OF MEAN SQUARE
 1                24.2143         4.03571         .60592
 2                18.3571         3.05952         .485654
 3                20.9286         3.4881          .542588
 4                18.3571         3.05952         .485654
 5                14.0486         2.34143         .369481
 6                8.71429         1.45238         .162081
 7                5.83429         .972381        -1.21636E-2

MEAN OF S↑2 = 2.62986     LOG OF MEAN S↑2 = .419933
DIFFERENCE = .300319
UNCORRECTED CHI SQUARE = 4.14908
DEGREES OF FREEDOM = 6

CORRECTED CHI SQUARE = 3.90138
```

```
20 DATA 7,7
30 DATA 6,5,4.5,4,4,3.5,3
40 DATA 5,4,3.5,3,2.8,2.5,2
50 DATA 4.5,3.5,3,2.5,2.3,2,1.5
60 DATA 3.5,3,2.5,2,1.8,1.5,1
70 DATA 3,2.5,2,1,.8,.7,.5
80 DATA 2.5,2,1,.8,.6,.4,.3
90 DATA 2,1.5,1,.5,.4,.3,.2

READY
RUN


HOMOG1     12:42   ATL TUE    06/18/74

 7 SAMPLES WITH 7 OBSERVATIONS EACH.
SAMPLE          SUM OF SQUARES MEAN SQUARE     LOG OF MEAN SQUARE
 1                5.92857        .988095         -5.20119E-3
 2                6.07714        1.01286          5.5482E-3
 3                6.07714        1.01286          5.5482E-3
 4                4.54857        .758095         -.120276
 5                5.88           .98             -8.77392E-3
 6                4.24857        .708095         -.149908
 7                2.81714        .469524         -.328342

MEAN OF S↑2 = .847075    LOG OF MEAN S↑2 =-7.20782E-2
DIFFERENCE = 9.68581E-2
UNCORRECTED CHI SQUARE = 1.33815
DEGREES OF FREEDOM = 6

CORRECTED CHI SQUARE = 1.25826


RUNNING TIME:    1.1 SECS   I/O TIME :     .4 SECS

READY
```

EXHIBIT 6

y = production rate
x_1 = slope
x_2 = fuel loading
x_3 = $(\text{slope})^2$
x_4 = $(\text{fuel loading})^2$
x_5 = (slope) (fuel loading)

Test H_0: $B_2 = 0$ at 95% CL also test H_0: $B_1 = B_2 = B_3 = B_4 = B_5 = 0$

ANOVA

Source	SS	df	MS	F
Regression due to x_1, x_2, x_3, x_4, x_5	857.64370	5	171.52874	86.822
Regression due to x_1, x_3, x_4, x_5	855.57357	4		
Gain due to x_2 after x_1, x_3, x_4, x_5	2.07013	1	2.07013	1.04783
Residual	278.5663	141	1.97563	
Total	1136.21	146		

$F_{.05}$, 1/141 = 3.91 - Accept H_0: $B_2 = 0$, $F_{.05}$, 5/141 = 2.28,
Reject H_0: $B_1 = B_2 = B_3 = B_4 = B_5 = 0$

Test H_0: $B_3 = 0$ at 95% CL after eliminating x_2
Also test H_0: $B_1 = B_3 = B_4 = B_5 = 0$

ANOVA

Source	SS	df	MS	F
Regression due to x_1, x_3, x_4, x_5	855.57357	4	213.89339	108.229
Regression due to x_1, x_4, x_5	847.6201	3		
Gain due to x_3 after x_1, x_4, x_5	7.95347	1	7.95347	4.02442
Residual	280.63643	142	1.97630	
Total	1136.21	146		

$F_{.05}$, 1/142 = 3.91 - Reject H_0: $B_3 = 0$

$F_{.05}$, 4/142 = 2.43 - Reject H_0: $B_1 = B_3 = B_4 = B_5 = 0$

Test H_0: $B_4 = 0$ at 95% CL after eliminating x_2

ANOVA

Source	SS	df	MS	F
Regression due to x_1, x_3, x_4, x_5	855.573	4		
Regression due to x_1, x_3, x_5	650.293	3		
Gain due to x_4 after x_1, x_3, x_5	205.280	1	205.28	103.871
Residual	280.63643	142	1.97630	
Total	1136.21	146		

$F_{.05}$, 1/142 = 3.91 Reject H_0: $B_4 = 0$

Test H_o: $B_1 = 0$ at 95% CL after eliminating x_2

ANOVA

Source	SS	df	MS	F
Regression due to x_1, x_3, x_4, x_5	855.57357	4		
Regression due to x_3, x_4, x_5	743.712	1		
Gain due to x_1 after x_3, x_4, x_5	111.862	1	111.862	56.602
Residual	280.63643	142	1.97630	
Total	1136.21	146		

$F_{.05}$, 1/142 = 3.91 Reject H_o: $B_1 = 0$

Test H_o: $B_5 = 0$ at 95% CL after eliminating x_2

ANOVA

Source	SS	df	MS	F
Regression due to x_1, x_3, x_4, x_5	855.57357	4		
Regression due to x_1, x_3, x_4	826.672	3		
Gain due to x_5 after x_1, x_3, x_4	28.902	1	28.902	14.624
Residual	280.63643	142	1.97630	
Total	1136.21	146		

$F_{.05}$, 1/142 = 3.91 Reject H_o: $B_5 = 0$

```
READY
LOAD ***STEPWI
READY
MERGE ***STEPWI,DATA
READY
1003 DIM Z(10,10),A(10),L(10),B(10),P(10),X(150,10)
1140 IF N > 150 THEN 5730
RUN

***STEPWI    09:59    06/18/74

TYPE THE NUMBER OF THE COLUMN CORRESPONDING TO THE
DEPENDENT VARIABLE(Y).?1
DO YOU WISH TO OMIT A VARIABLE(XK) FROM THE ANALYSIS?0
STEP  1
VARIABLE SELECTED IS ... X 6 (interaction) = X5 in ANOVA
SUM OF SQUARES REDUCED IN THIS STEP.... 588.937 = Regression SS
PROPORTION OF VARIABLE OF Y REDUCED.... .518335
PARTIAL F (D.F. = 1, 145 )............. 156.039
CUMULATIVE SUM OF SQUARES REDUCED...... 588.937
CUMULATIVE PROPORTION REDUCED.......... .518335 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .719955
F FOR ANALYSIS OF VAR. (D.F. = 1 , 145 ) 156.039
STANDARD ERROR OF ESTIMATE............. 1.94275
VARIABLE        REG. COEFF.    STD.ERR-COEFF.   COMPUTED T
   6            -4.04861E-3     3.24107E-4      -12.4916
INTERCEPT(A)   6.66894
STEP  2
VARIABLE SELECTED IS ... X 2 (slope) = X1
SUM OF SQUARES REDUCED IN THIS STEP.... 53.4031
PROPORTION OF VARIABLE OF Y REDUCED.... 4.70012E-2
PARTIAL F (D.F. = 1, 144 )............. 15.5711
DO YOU WISH TO ENTER THIS VARIABLE IN THE REGRESSION?1
CUMULATIVE SUM OF SQUARES REDUCED...... 642.34
CUMULATIVE PROPORTION REDUCED.......... .565337 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .751889
F FOR ANALYSIS OF VAR. (D.F. = 2 , 144 ) 93.6454
STANDARD ERROR OF ESTIMATE............. 1.85193
VARIABLE        REG. COEFF.    STD.ERR-COEFF.   COMPUTED T
   6            -2.92703E-3     4.1981E-4       -6.97227
   2            -7.34032E-2     1.86018E-2      -3.94602
INTERCEPT(A)   7.43566
STEP  3
VARIABLE SELECTED IS ... X 5 (fuel)^2 = X4
SUM OF SQUARES REDUCED IN THIS STEP.... 205.28
PROPORTION OF VARIABLE OF Y REDUCED.... .180671
PARTIAL F (D.F. = 1, 143 )............. 101.719
DO YOU WISH TO ENTER THIS VARIABLE IN THE REGRESSION?1
CUMULATIVE SUM OF SQUARES REDUCED...... 847.62
CUMULATIVE PROPORTION REDUCED.......... .746008 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .863717
F FOR ANALYSIS OF VAR. (D.F. = 3 , 143 ) 140.003
STANDARD ERROR OF ESTIMATE............. 1.4206
VARIABLE        REG. COEFF.    STD.ERR-COEFF.   COMPUTED T
   6             2.31329E-3     6.11288E-4       3.78429
   2            -.230613        2.11325E-2      -10.9127
   5            -2.24816E-3     2.22908E-4      -10.0856
INTERCEPT(A)   10.0585
```

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STEP  4
VARIABLE SELECTED IS ... X 4  (slope)^2 = X3
SUM OF SQUARES REDUCED IN THIS STEP.... 7.95347
PROPORTION OF VARIABLE OF Y REDUCED.... 7.00001E-3
PARTIAL F (D.F. = 1, 142 )............. 4.02442
DO YOU WISH TO ENTER THIS VARIABLE IN THE REGRESSION?1
CUMULATIVE SUM OF SQUARES REDUCED...... 855.573
CUMULATIVE PROPORTION REDUCED.......... .753008 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .86776
F FOR ANALYSIS OF VAR. (D.F. = 4 , 142 ) 108.229
STANDARD ERROR OF ESTIMATE............. 1.40581
VARIABLE        REG. COEFF.   STD.ERR-COEFF.   COMPUTED T
   6             2.31329E-3      6.04924E-4       3.8241
   2            -.298141         3.96287E-2      -7.52337
   5            -2.24816E-3      2.20587E-4     -10.1917
   4             1.90705E-3      9.50625E-4       2.0061
INTERCEPT(A)   10.4141
STEP  5
VARIABLE SELECTED IS ... X 3  fuel = X2
SUM OF SQUARES REDUCED IN THIS STEP.... 2.07013
PROPORTION OF VARIABLE OF Y REDUCED.... 1.82197E-3
PARTIAL F (D.F. = 1, 141 )............. 1.04783
DO YOU WISH TO ENTER THIS VARIABLE IN THE REGRESSION?1
CUMULATIVE SUM OF SQUARES REDUCED...... 857.643
CUMULATIVE PROPORTION REDUCED.......... .75483 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .868809
F FOR ANALYSIS OF VAR. (D.F. = 5 , 141 ) 86.822
STANDARD ERROR OF ESTIMATE............. 1.40557
VARIABLE        REG. COEFF.   STD.ERR-COEFF.   COMPUTED T
   6             2.51553E-3      6.36273E-4       3.95354
   2            -.304208         4.00628E-2      -7.59327
   5            -1.66071E-3      6.1481E-4       -2.70117
   4             1.90705E-3      9.50465E-4       2.00643
   3            -.040453         3.95189E-2      -1.02364
INTERCEPT(A)   10.9424
DO YOU WISH TO PRINT THE TABLE OF RESIDUALS?0
DO YOU WISH TO COMPUTE MORE REGRESSION?1
TYPE THE NUMBER OF THE COLUMN CORRESPONDING TO THE
DEPENDENT VARIABLE(Y).?1
DO YOU WISH TO OMIT A VARIABLE(XK) FROM THE ANALYSIS?1
WHEN REQUESTED, ENTER THE COLUMN CORRESPONDING TO THE
VARIABLE TO BE OMITTED. TYPE 0 TO TERMINATE THE REQUESTS.
VARIABLE, PLEASE?3
VARIABLE, PLEASE?0
STEP  1
VARIABLE SELECTED IS ... X 6
SUM OF SQUARES REDUCED IN THIS STEP.... 588.937
PROPORTION OF VARIABLE OF Y REDUCED.... .518335
PARTIAL F (D.F. = 1, 145 )............. 156.039
CUMULATIVE SUM OF SQUARES REDUCED...... 588.937
CUMULATIVE PROPORTION REDUCED.......... .518335 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .719955
F FOR ANALYSIS OF VAR. (D.F. = 1 , 145 ) 156.039
STANDARD ERROR OF ESTIMATE............. 1.94275
VARIABLE        REG. COEFF.   STD.ERR-COEFF.   COMPUTED T
   6            -4.04861E-3      3.24107E-4     -12.4916
INTERCEPT(A)   6.66894
TYPE THE NUMBER OF THE COLUMN CORRESPONDING TO THE
DEPENDENT VARIABLE(Y).?1
DO YOU WISH TO OMIT A VARIABLE(XK) FROM THE ANALYSIS?1
WHEN REQUESTED, ENTER THE COLUMN CORRESPONDING TO THE
VARIABLE TO BE OMITTED. TYPE 0 TO TERMINATE THE REQUESTS.
VARIABLE, PLEASE?3
VARIABLE, PLEASE?0
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STEP  2
VARIABLE SELECTED IS ... X 2
SUM OF SQUARES REDUCED IN THIS STEP.... 53.4031
PROPORTION OF VARIABLE OF Y REDUCED.... 4.70012E-2
PARTIAL F (D.F. = 1, 144 ).............. 15.5711
DO YOU WISH TO ENTER THIS VARIABLE IN THE REGRESSION?1
CUMULATIVE SUM OF SQUARES REDUCED...... 642.34
CUMULATIVE PROPORTION REDUCED.......... .565337 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .751889
F FOR ANALYSIS OF VAR. (D.F. = 2 , 144 ) 93.6454
STANDARD ERROR OF ESTIMATE............. 1.85193
VARIABLE         REG. COEFF.   STD.ERR-COEFF.   COMPUTED T
   6             -2.92703E-3     4.1981E-4       -6.97227
   2             -7.34032E-2     1.86018E-2      -3.94602
INTERCEPT(A)   7.43566
STEP  3
VARIABLE SELECTED IS ... X 5
SUM OF SQUARES REDUCED IN THIS STEP.... 205.28
PROPORTION OF VARIABLE OF Y REDUCED.... .180671
PARTIAL F (D.F. = 1, 143 ).............. 101.719
DO YOU WISH TO ENTER THIS VARIABLE IN THE REGRESSION?1
CUMULATIVE SUM OF SQUARES REDUCED...... 847.62
CUMULATIVE PROPORTION REDUCED.......... .746008 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .863717
F FOR ANALYSIS OF VAR. (D.F. = 3 , 143 ) 140.003
STANDARD ERROR OF ESTIMATE............. 1.4206
VARIABLE         REG. COEFF.   STD.ERR-COEFF.   COMPUTED T
   6              2.31329E-3     6.11288E-4       3.78429
   2             -.230613        2.11325E-2      -10.9127
   5             -2.24816E-3     2.22908E-4      -10.0856
INTERCEPT(A)   10.0585
STEP  4
VARIABLE SELECTED IS ... X 4
SUM OF SQUARES REDUCED IN THIS STEP.... 7.95347
PROPORTION OF VARIABLE OF Y REDUCED.... 7.00001E-3
PARTIAL F (D.F. = 1, 142 ).............. 4.02442
DO YOU WISH TO ENTER THIS VARIABLE IN THE REGRESSION?1
CUMULATIVE SUM OF SQUARES REDUCED...... 855.573
CUMULATIVE PROPORTION REDUCED.......... .753008 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .86776
F FOR ANALYSIS OF VAR. (D.F. = 4 , 142 ) 108.229
STANDARD ERROR OF ESTIMATE............. 1.40581
VARIABLE         REG. COEFF.   STD.ERR-COEFF.   COMPUTED T
   6              2.31329E-3     6.04924E-4       3.8241
   2             -.298141        3.96287E-2      -7.52337
   5             -2.24816E-3     2.20587E-4      -10.1917
   4              1.90705E-3     9.50625E-4       2.0061
INTERCEPT(A)   10.4141
DO YOU WISH TO PRINT THE TABLE OF RESIDUALS?0
DO YOU WISH TO COMPUTE MORE REGRESSION?1
STEP  1
VARIABLE SELECTED IS ... X 6
SUM OF SQUARES REDUCED IN THIS STEP.... 588.937
PROPORTION OF VARIABLE OF Y REDUCED.... .518335
PARTIAL F (D.F. = 1, 145 ).............. 156.039
CUMULATIVE SUM OF SQUARES REDUCED...... 588.937
CUMULATIVE PROPORTION REDUCED.......... .518335 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .719955
F FOR ANALYSIS OF VAR. (D.F. = 1 , 145 ) 156.039
STANDARD ERROR OF ESTIMATE............. 1.94275
VARIABLE         REG. COEFF.   STD.ERR-COEFF.   COMPUTED T
   6             -4.04861E-3     3.24107E-4      -12.4916
INTERCEPT(A)   6.66894
```

```
STEP  2
VARIABLE SELECTED IS ... X 2
SUM OF SQUARES REDUCED IN THIS STEP.... 53.4031
@

NOW AT 3410

READY
GO TO 1
TYPE THE NUMBER OF THE COLUMN CORRESPONDING TO THE
DEPENDENT VARIABLE(Y).?1
DO YOU WISH TO OMIT A VARIABLE(XK) FROM THE ANALYSIS?1
WHEN REQUESTED, ENTER THE COLUMN CORRESPONDING TO THE
VARIABLE TO BE OMITTED. TYPE 0 TO TERMINATE THE REQUESTS.
VARIABLE, PLEASE?3
VARIABLE, PLEASE?5
VARIABLE, PLEASE?0
STEP  1
VARIABLE SELECTED IS ... X 6
SUM OF SQUARES REDUCED IN THIS STEP.... 588.937
PROPORTION OF VARIABLE OF Y REDUCED.... .518335
PARTIAL F (D.F. = 1, 145 )............. 156.039
CUMULATIVE SUM OF SQUARES REDUCED...... 588.937
CUMULATIVE PROPORTION REDUCED.......... .518335 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .719955
F FOR ANALYSIS OF VAR. (D.F. = 1 , 145 ) 156.039
STANDARD ERROR OF ESTIMATE............ 1.94275
VARIABLE        REG. COEFF.   STD.ERR-COEFF.   COMPUTED T
   6            -4.04861E-3    3.24107E-4    -12.4916
INTERCEPT(A)  6.66894
STEP  2
VARIABLE SELECTED IS ... X 2
SUM OF SQUARES REDUCED IN THIS STEP.... 53.4031
PROPORTION OF VARIABLE OF Y REDUCED.... 4.70012E-2
PARTIAL F (D.F. = 1, 144 )............. 15.5711
DO YOU WISH TO ENTER THIS VARIABLE IN THE REGRESSION?1
CUMULATIVE SUM OF SQUARES REDUCED...... 642.34
CUMULATIVE PROPORTION REDUCED.......... .565337 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .751889
F FOR ANALYSIS OF VAR. (D.F. = 2 , 144 ) 93.6454
STANDARD ERROR OF ESTIMATE............ 1.85193
VARIABLE        REG. COEFF.   STD.ERR-COEFF.   COMPUTED T
   6            -2.92703E-3    4.1981E-4     -6.97227
   2            -7.34032E-2    1.86018E-2    -3.94602
INTERCEPT(A)  7.43566
STEP  3
VARIABLE SELECTED IS ... X 4
SUM OF SQUARES REDUCED IN THIS STEP.... 7.95347
PROPORTION OF VARIABLE OF Y REDUCED.... 7.00001E-3
PARTIAL F (D.F. = 1, 143 )............. 2.34063
DO YOU WISH TO ENTER THIS VARIABLE IN THE REGRESSION?1
CUMULATIVE SUM OF SQUARES REDUCED...... 650.293
CUMULATIVE PROPORTION REDUCED.......... .572337 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .756529
F FOR ANALYSIS OF VAR. (D.F. = 3 , 143 ) 63.7917
STANDARD ERROR OF ESTIMATE............ 1.84337
VARIABLE        REG. COEFF.   STD.ERR-COEFF.   COMPUTED T
   6            -2.92703E-3    4.17869E-4    -7.00465
   2            -.140931       .047865       -2.94435
   4             1.90705E-3    1.24651E-3     1.52991
INTERCEPT(A)  7.79128
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DO YOU WISH TO PRINT THE TABLE OF RESIDUALS?0
DO YOU WISH TO COMPUTE MORE REGRESSION?1
TYPE THE NUMBER OF THE COLUMN CORRESPONDING TO THE
DEPENDENT VARIABLE(Y).?1
DO YOU WISH TO OMIT A VARIABLE(XK) FROM THE ANALYSIS?1
WHEN REQUESTED, ENTER THE COLUMN CORRESPONDING TO THE
VARIABLE TO BE OMITTED. TYPE 0 TO TERMINATE THE REQUESTS.
VARIABLE, PLEASE?2
VARIABLE, PLEASE?3
VARIABLE, PLEASE?0
STEP  1
VARIABLE SELECTED IS ... X 6
SUM OF SQUARES REDUCED IN THIS STEP.... 588.937
PROPORTION OF VARIABLE OF Y REDUCED.... .518335
PARTIAL F (D.F. = 1, 145 )............. 156.039
CUMULATIVE SUM OF SQUARES REDUCED...... 588.937
CUMULATIVE PROPORTION REDUCED.......... .518335 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .719955
F FOR ANALYSIS OF VAR. (D.F. = 1 , 145 ) 156.039
STANDARD ERROR OF ESTIMATE............. 1.94275
VARIABLE         REG. COEFF.   STD.ERR-COEFF.   COMPUTED T
   6             -4.04861E-3     3.24107E-4     -12.4916
INTERCEPT(A)   6.66894
STEP  2
VARIABLE SELECTED IS ... X 4
SUM OF SQUARES REDUCED IN THIS STEP.... 31.8985
PROPORTION OF VARIABLE OF Y REDUCED.... 2.80746E-2
PARTIAL F (D.F. = 1, 144 )............. 8.91275
DO YOU WISH TO ENTER THIS VARIABLE IN THE REGRESSION?1
CUMULATIVE SUM OF SQUARES REDUCED...... 620.835
CUMULATIVE PROPORTION REDUCED.......... .54641 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .739195
F FOR ANALYSIS OF VAR. (D.F. = 2 , 144 ) 86.7337
STANDARD ERROR OF ESTIMATE............. 1.89182
VARIABLE         REG. COEFF.   STD.ERR-COEFF.   COMPUTED T
   6             -3.24926E-3     4.13883E-4     -7.85069
   4             -1.47739E-3     4.94867E-4     -2.98542
INTERCEPT(A)   6.93988
STEP  3
VARIABLE SELECTED IS ... X 5
SUM OF SQUARES REDUCED IN THIS STEP.... 122.877
PROPORTION OF VARIABLE OF Y REDUCED.... .108147
PARTIAL F (D.F. = 1, 143 )............. 44.7685
DO YOU WISH TO ENTER THIS VARIABLE IN THE REGRESSION?1
CUMULATIVE SUM OF SQUARES REDUCED...... 743.712
CUMULATIVE PROPORTION REDUCED.......... .654557 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .809047
F FOR ANALYSIS OF VAR. (D.F. = 3 , 143 ) 90.3203
STANDARD ERROR OF ESTIMATE............. 1.65672
VARIABLE         REG. COEFF.   STD.ERR-COEFF.   COMPUTED T
   6              2.29155E-4     6.33747E-4      .361587
   4             -4.16795E-3     5.91193E-4     -7.05005
   5             -1.60219E-3     2.39456E-4     -6.69093
INTERCEPT(A)   8.13225
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DO YOU WISH TO PRINT THE TABLE OF RESIDUALS?0
DO YOU WISH TO COMPUTE MORE REGRESSION?1
TYPE THE NUMBER OF THE COLUMN CORRESPONDING TO THE
DEPENDENT VARIABLE(Y).?1
DO YOU WISH TO OMIT A VARIABLE(XK) FROM THE ANALYSIS?1
WHEN REQUESTED, ENTER THE COLUMN CORRESPONDING TO THE
VARIABLE TO BE OMITTED. TYPE 0 TO TERMINATE THE REQUESTS.
VARIABLE, PLEASE?3
VARIABLE, PLEASE?6
VARIABLE, PLEASE?0
STEP  1
VARIABLE SELECTED IS ... X 2
SUM OF SQUARES REDUCED IN THIS STEP.... 475.616
PROPORTION OF VARIABLE OF Y REDUCED.... .4186
PARTIAL F (D.F. = 1, 145 )............... 104.398
CUMULATIVE SUM OF SQUARES REDUCED...... 475.616
CUMULATIVE PROPORTION REDUCED.......... .4186 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .646993
F FOR ANALYSIS OF VAR. (D.F. = 1 , 145 ) 104.398
STANDARD ERROR OF ESTIMATE............. 2.13443
VARIABLE         REG. COEFF.   STD.ERR-COEFF.   COMPUTED T
   2             -.161214         1.57782E-2     -10.2175
INTERCEPT(A)   7.43566
STEP  2
VARIABLE SELECTED IS ... X 5
SUM OF SQUARES REDUCED IN THIS STEP.... 343.102
PROPORTION OF VARIABLE OF Y REDUCED.... .301972
PARTIAL F (D.F. = 1, 144 )............... 155.617
DO YOU WISH TO ENTER THIS VARIABLE IN THE REGRESSION?1
CUMULATIVE SUM OF SQUARES REDUCED...... 818.719
CUMULATIVE PROPORTION REDUCED.......... .720571 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .848865
F FOR ANALYSIS OF VAR. (D.F. = 2 , 144 ) 185.669
STANDARD ERROR OF ESTIMATE............. 1.48485
VARIABLE         REG. COEFF.   STD.ERR-COEFF.   COMPUTED T
   2             -.161214         1.09763E-2     -14.6874
   5             -1.53116E-3      1.22742E-4     -12.4747
INTERCEPT(A)   9.22201
STEP  3
VARIABLE SELECTED IS ... X 4
SUM OF SQUARES REDUCED IN THIS STEP.... 7.95347
PROPORTION OF VARIABLE OF Y REDUCED.... 7.00001E-3
PARTIAL F (D.F. = 1, 143 )............... 3.67436
DO YOU WISH TO ENTER THIS VARIABLE IN THE REGRESSION?1
CUMULATIVE SUM OF SQUARES REDUCED...... 826.672
CUMULATIVE PROPORTION REDUCED.......... .727571 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .852978
F FOR ANALYSIS OF VAR. (D.F. = 3 , 143 ) 127.303
STANDARD ERROR OF ESTIMATE............. 1.47125
VARIABLE         REG. COEFF.   STD.ERR-COEFF.   COMPUTED T
   2             -.228742         3.68691E-2     -6.20417
   5             -1.53116E-3      1.21617E-4     -12.59
   4              1.90705E-3      9.94879E-4      1.91686
INTERCEPT(A)   9.57763
```

```
DO YOU WISH TO PRINT THE TABLE OF RESIDUALS?0
DO YOU WISH TO COMPUTE MORE REGRESSION?1
TYPE THE NUMBER OF THE COLUMN CORRESPONDING TO THE
DEPENDENT VARIABLE(Y).?1
DO YOU WISH TO OMIT A VARIABLE(XK) FROM THE ANALYSIS?1
WHEN REQUESTED, ENTER THE COLUMN CORRESPONDING TO THE
VARIABLE TO BE OMITTED. TYPE 0 TO TERMINATE THE REQUESTS.
VARIABLE, PLEASE?3
VARIABLE, PLEASE?4
VARIABLE, PLEASE?0
STEP  1
VARIABLE SELECTED IS ... X 6
SUM OF SQUARES REDUCED IN THIS STEP.... 588.937
PROPORTION OF VARIABLE OF Y REDUCED.... .518335
PARTIAL F (D.F. = 1, 145 )............... 156.039
CUMULATIVE SUM OF SQUARES REDUCED...... 588.937
CUMULATIVE PROPORTION REDUCED.......... .518335 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .719955
F FOR ANALYSIS OF VAR. (D.F. = 1 , 145 ) 156.039
STANDARD ERROR OF ESTIMATE............. 1.94275
VARIABLE        REG. COEFF.    STD.ERR-COEFF.   COMPUTED T
   6            -4.04861E-3      3.24107E-4      -12.4916
INTERCEPT(A)   6.66894
STEP  2
VARIABLE SELECTED IS ... X 2
SUM OF SQUARES REDUCED IN THIS STEP.... 53.4031
PROPORTION OF VARIABLE OF Y REDUCED.... 4.70012E-2
PARTIAL F (D.F. = 1, 144 )............... 15.5711
DO YOU WISH TO ENTER THIS VARIABLE IN THE REGRESSION?1
CUMULATIVE SUM OF SQUARES REDUCED...... 642.34
CUMULATIVE PROPORTION REDUCED.......... .565337 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .751889
F FOR ANALYSIS OF VAR. (D.F. = 2 , 144 ) 93.6454
STANDARD ERROR OF ESTIMATE............. 1.85193
VARIABLE        REG. COEFF.    STD.ERR-COEFF.   COMPUTED T
   6            -2.92703E-3      4.1981E-4       -6.97227
   2            -7.34032E-2      1.86018E-2      -3.94602
INTERCEPT(A)   7.43566
STEP  3
VARIABLE SELECTED IS ... X 5
SUM OF SQUARES REDUCED IN THIS STEP.... 205.28
PROPORTION OF VARIABLE OF Y REDUCED.... .180671
PARTIAL F (D.F. = 1, 143 )............... 101.719
DO YOU WISH TO ENTER THIS VARIABLE IN THE REGRESSION?1
CUMULATIVE SUM OF SQUARES REDUCED...... 847.62
CUMULATIVE PROPORTION REDUCED.......... .746008 (OF 1136.21 )
MULTIPLE CORELATION COEFFICIENT........ .863717
F FOR ANALYSIS OF VAR. (D.F. = 3 , 143 ) 140.003
STANDARD ERROR OF ESTIMATE............. 1.4206
VARIABLE        REG. COEFF.    STD.ERR-COEFF.   COMPUTED T
   6             2.31329E-3      6.11288E-4       3.78429
   2            -.230613         2.11325E-2      -10.9127
   5            -2.24816E-3      2.22908E-4      -10.0856
INTERCEPT(A)   10.0585
DO YOU WISH TO PRINT THE TABLE OF RESIDUALS?0
DO YOU WISH TO COMPUTE MORE REGRESSION?0

END OF STEPWI
NOW AT END
READY
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